

Access to Algebra I: The Effects of Online Mathematics for Grade 8 Students



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Executive Summary

This report presents findings from a randomized control trial designed to inform the decisions of policymakers who are considering using online courses to provide access to Algebra I in grade 8. It focuses on students judged by their schools to be ready to take Algebra I in grade 8 but who attend schools that do not offer the course. The study tested the impact of offering an online Algebra I course on students' algebra achievement at the end of grade 8 and their subsequent likelihood of participating in an advanced mathematics course sequence in high school. The study was designed to respond to both broad public interest in the deployment of online courses for K–12 students and to calls from policymakers to provide students with adequate pathways to advanced coursetaking sequences in mathematics (National Mathematics Advisory Panel 2008).

Policymakers have persistently called for broadening access to Algebra I in grade 8. A 2008 report by the National Mathematics Advisory Panel recommended that “all prepared students [should] have access to an authentic algebra course—and [that districts] should prepare more students than at present to enroll in such a course by Grade 8” (2008, p. 23).² This recommendation echoed one made more than 10 years earlier by the U.S. Department of Education, which asserted that all states should invest in expanding access to Algebra I for middle school students (U.S. Department of Education 1997).

These policy statements are built on two bodies of research. One demonstrates that Algebra I operates as a gateway to more advanced mathematics courses in high school and college. The other suggests that students who succeed in Algebra I in middle school have more success in mathematics throughout high school and college than students who take Algebra I later (Nord et al. 2011; Smith 1996; Spielhagen 2006; Stevenson, Schiller, and Schneider 1994). Given these findings, federal, state, and local policymakers have sought to expand access to Algebra I during the past two decades.

National grade 8 Algebra I enrollments increased from 16% in the 1990s to 31% in 2007 (Loveless 2008), and in general, prior mathematics achievement is related to whether or not students take Algebra I in grade 8 (Walston and Carlivati McCarroll 2010). However, not all high-achieving students have the opportunity to take Algebra I in grade 8. An analysis of data from the Early Childhood Longitudinal Study (ECLS-K; U.S. Department of Education 2009a) indicated that nationally, approximately 25% of students who scored in the highest quartile on the grade 5 mathematics assessment were not enrolled in a formal Algebra I course in grade 8 (Walston and Carlivati McCarroll 2010).

Additional analysis of ECLS-K data (U.S. Department of Education 2009a) indicated that in rural schools, a larger proportion of high-achieving students do not take Algebra I in grade 8 than in urban or suburban schools—39% of students who scored in the highest quartile on the grade 5 assessment were not enrolled in Algebra I in grade 8. Furthermore, analysis of school-level administrator data from the ECLS-K indicated that while nationally, 16% of schools do not offer Algebra I to grade 8 students, the rates are highest in rural schools. About 24% of rural schools do not offer Algebra I in grade 8, compared with 21% of urban schools and 9% of suburban schools.

² An “authentic” algebra course is one that covers symbols and expressions, linear equations, quadratic equations, functions, the algebra of polynomials, and combinatorics/finite probability.

In schools that do not offer Algebra I, curriculum offerings may be limited by constraints such as staffing, space, and enrollments—issues that are particularly challenging in small or rural schools, where student populations are low and attracting qualified and experienced teachers is difficult (Hammer, Hughes, McClure, Reeves, and Salgado 2005; Jimerson 2006). As technology capacity increases in schools around the country, online courses are increasingly seen as a viable means for expanding curricular offerings and broadening access to key courses, especially in small and rural schools (Hanum, Irvin, Banks, and Farmer 2009; Picciano and Seaman 2009; Schwartzbeck, Prince, Redfield, Morris, and Hammer 2003).

This study tested the impact of expanding access to Algebra I to grade 8 students by offering an online course in schools that do not typically offer Algebra I in grade. It is the first randomized control trial testing the impact of providing an online Algebra I course on students' mathematics achievement and coursetaking trajectories over time.

Goals and Research Questions

The primary goal of the study was to measure the effects of offering an online Algebra I course to algebra-ready (AR) students in grade 8 in schools that do not typically offer the course. The primary research questions asked whether access to online Algebra I improves AR students' knowledge of algebra in the short term and whether it opens doors to more advanced mathematics course sequences in the longer term. The specific primary research questions were:

1. What is the impact of offering an online Algebra I course to AR students on their algebra achievement at the end of grade 8?
2. How does offering an online Algebra I course to AR students affect their likelihood of participating in an advanced course sequence in high school?

The secondary goal of the study was to estimate whether there are potential unintended consequences (or side effects) of offering online Algebra I to AR students. Offering the online Algebra I course may affect these students in unintended ways. Taking an online Algebra I instead of general grade 8 mathematics may, for example, adversely affect AR students' general mathematics achievement. Providing online Algebra I to AR students may also have unintended consequences for non-algebra ready (N-AR) students—the students who remain in the general mathematics course. For example, when the AR students are removed from the general grade 8 mathematics class, outcomes for the remaining students may be affected because of peer effects; smaller class sizes; a change in course emphasis (for example, less algebra); or other reasons.

Four secondary research questions examined these issues:

3. What is the effect of providing online Algebra I to AR students on their general mathematics achievement at the end of grade 8?
4. What is the effect of providing online Algebra I to AR students on the algebra achievement of N-AR students at the end of grade 8?
5. What is the effect of providing online Algebra I to AR students on the general mathematics achievement of N-AR students at the end of grade 8?
6. How does offering an online Algebra I course to AR students affect the likelihood that N-AR students follow an intermediate course sequence in high school?

By answering the primary and secondary research questions, this study examined what happens to the entire population of grade 8 students—including potential benefits and possible negative consequences—when a school uses an online course as a way to offer Algebra I to AR students. The study thus sought to inform decision makers who are considering investing in an online course as a means to broaden access to Algebra I in grade 8.

The study also posed two exploratory questions that further examine the impact of online Algebra I on AR students' high school coursetaking:

7. How does access to online Algebra I in grade 8 affect the likelihood that AR students sign up for advanced courses in grade 9?
8. How does access to online Algebra I in grade 8 affect the likelihood that AR students “double up,” or take more than one mathematics course per year, in grade 9 or 10?

Study Design, Samples, and Measures

This study is a randomized experimental trial. Schools in Maine and Vermont that did not typically offer a full section of Algebra I to grade 8 students as of the 2007/08 school year were eligible for the study. Initial recruitment—including determination of eligibility and interest in participation—focused on all public schools in Maine that serve grade 8 students (a total of 224 schools as of fall 2007). Later recruitment focused on approximately 40 schools in Vermont that state administrators and local educators thought would be most likely to be eligible. A total of 68 schools were eligible, agreed to participate in the study, and met the study's requirement to identify their AR students before the schools were randomly assigned to condition. Most of these schools—61 out of 68—were classified as rural schools by the Common Core of Data, maintained by the National Center for Education Statistics (<http://nces.ed.gov/ccd/>). In 76% of the schools, the grade span served was either pre-K–8 or K–8. As of the 2007/08 school year, grade 8 enrollments ranged from fewer than 4 students to nearly 150 students; the average was 32 students. At the beginning of the 2008/09 academic year, 445 students had been identified the prior spring by their schools as AR, with an average of 6.5 AR students per school.

Schools were randomly assigned to one of two study groups. Schools in the treatment condition received the online Algebra I course to offer to their AR students during the 2008/09 school year. Schools in the control condition did not receive the online Algebra I course during the 2008/09 school year and implemented their usual mathematics curriculum.

The first analytic sample included 440 AR students who attended the participating schools in Maine and Vermont as grade 8 students in 2008/09 (218 in treatment schools, 222 in control schools). At the start of the 2008/09 school year (August 2008), 445 students had been designated algebra ready the previous June and were enrolled in the study schools. Five of these 445 students were excluded because their parents did not consent to their participation in the study. Of the 218 AR students who attended treatment schools, 211 (97%) enrolled in the online Algebra I course. The second analytic sample included 1,445 N–AR students (744 in treatment schools, 701 in control schools) who were in grade 8 in 2008/09.

Two baseline achievement measures of general mathematics were available for all students. The first was the state mathematics assessment, taken by all students in the year before the study. These scores, collected from the states and districts, were available for more than 97% of

students. The second measure was a computer-adaptive pretest administered to all students in the study schools at the beginning of grade 8. The pretest—the Promise Assessment (Internet Testing Systems and SEG Assessment, 2009)—included 30 items drawn from an item bank of more than 1,000 items ranging in difficulty from the grade 5 to the grade 8 level. Response rates on the pretest exceeded 96% for both AR and N–AR students.³

The outcome measures were mathematics achievement and subsequent mathematics coursetaking. The mathematics achievement measures included two assessments administered at the end of grade 8 to all students. One assessment measured algebra knowledge; the other assessment measured general mathematics achievement. Each assessment was computer adaptive and included 20 items. The algebra assessment was scaled from 400 to 500; the general mathematics assessment was scaled from 200 to 400. Response rates for AR students were 99% on both the algebra and the general mathematics test. For N–AR students, response rates were 86% for algebra and 93% for general mathematics.⁴

Research by Stevenson et al. (1994) and Schneider, Swanson, and Riegle-Crumb (1998) was used to code coursetaking sequences as “advanced” and “intermediate.” Data were collected at two time points. The first time point was the end of grade 8 (2009), when data were collected on students’ planned grade 9 courses (based on registrations). These data, collected to address the research questions on planned coursetaking, were available for 96% of the AR sample and 92% of the N–AR sample. For AR students, planned courses were coded as advanced if the student planned to enroll in a course above Algebra I in grade 9. For N–AR students, planned coursetaking was coded as intermediate if the student planned to enroll in Algebra I or a higher course in grade 9.

The second time point was the end of grade 9 (2010), when data were collected for AR students only. These data included the grade 9 course names, student grades in their courses, and planned grade 10 courses (based on registrations). Codeable course data were collected for 97% of AR students. The high school course sequences were coded as advanced if the students successfully completed a full-year course above Algebra I in grade 9 with a grade of C or higher and enrolled in the next course in the sequence for grade 10.

Description of the Intervention and Its Implementation

The online Algebra I course used in the study is a completely web-based course offered by Class.com, based in Lincoln, Nebraska. The Algebra I course was one of Class.com’s existing products. As implemented for the study, the online Algebra I course had three instructional components: the online course software, an online teacher (provided by Class.com), and an on-site proctor (provided by the school).

³ The Promise Assessment pretest was administered after random assignment. Although there were no differences by condition observed on the prior year’s state mathematics assessment, there were differences on the pretest that seemed to be related to random assignment condition. Students in treatment schools outperformed students in control schools and spent significantly more time on the computer-based test. Because of the bias this post-random assignment difference could introduce into the analyses, the state mathematics assessment was used as the measure of baseline mathematics achievement for the main analyses.

⁴ Scores based on less than five minutes of test-taking were determined to be invalid and dropped from analysis. A total of 118 algebra posttest scores were dropped from the N–AR sample for this reason (73 in the treatment group, 45 in the control group). Multiple imputation was used to handle missing data.

Researchers determined that the topics covered in Class.com’s Algebra I course were similar to those in typical Algebra I textbooks used in the region. The material for each topic is presented in the form of an electronic, interactive textbook that consists of computerized direct instruction; guided practice (“your-turn” problems) and practice problem sets, both with automated feedback; and quizzes and exams that provide immediate scores. Other activities include demonstrations of content materials; audio clips; interactive applets that present questions and guided solutions; a messaging feature through which students can send and receive messages from the online teachers; and a discussion board to which students can post questions and comments.

Students taking the online course were assigned to a specific course section and taught by an online teacher hired, trained, and supervised by Class.com. The online teacher was responsible for providing instruction and supporting student learning.

Participating schools were required to provide a school staff member to serve as an on-site proctor, who would supervise and support students while they were using the online course. The proctor did not have to be a mathematics teacher and was not required to provide instruction. Proctors were expected to supervise students’ behavior, serve as a contact person for students and parents, proctor quizzes and exams, and act as a liaison between the online teacher and the school, students, and parents.

A total of 242 students enrolled in the online course (211 AR students and an additional 31 N–AR students placed into the course by their schools after random assignment). Students within schools were enrolled in one of 10 course sections, with an average of 24 students per section. In 80% of treatment schools, the regular grade 8 mathematics teacher served as the proctor. In 69% of treatment schools, students taking the online course sat in the same classroom as students taking the regular grade 8 mathematics class.

Analyses of archived data from the online course management system and data from weekly proctor logs showed that the types and amount of interaction between online course participants and their teachers and proctors did not match the initial expectations for the intervention. Online teachers spent less time communicating directly with students about the course than expected, and on-site proctors spent more time communicating with students about mathematics than expected. Participating students varied in the amount of the course content they completed: 43% of AR students completed a full Algebra I course, and 82% completed more than half the course.

Description of the Counterfactual

The counterfactual in the study was the “business as usual” grade 8 mathematics class taught in the control schools. As expected, based on review of both states’ standards for grade 8 mathematics, students who took the general grade 8 mathematics class in control schools were taught algebra content. Analysis of course materials suggested that in 16 of 33 control schools that provided materials, the general mathematics classes had a curricular focus on algebraic content of 75% or higher, and 94% of the control schools had a curricular focus on algebraic content of 50% or higher. In more than half of control schools (55%), AR and N–AR students received instruction in the same mathematics classes; in 33% of control schools, AR and N–AR students were in separate classes (four control schools had no N–AR students).

Although the expected counterfactual was the absence of access to a formal Algebra I course in grade 8, in seven control schools, AR students took a separate Algebra I course that was taught at the local middle school or high school. Across all control schools, 45 AR students (20% of the AR control sample) took an Algebra I course in grade 8. During the recruitment process, four schools were deemed eligible for the study even though they allowed grade 8 students to take Algebra I at the local high school if they determined that students were ready and scheduling arrangements were possible. Nevertheless, researchers did not expect the percentage of AR students in control schools who took the course to be as high as it was.

It is possible that the introduction of the study and its emphasis on Algebra I for grade 8 students into these schools changed the nature of offerings to students in control schools. However, without another comparison group of schools that was completely unaffected by the study, there is no way to know whether this assertion is true.

Analytic Approach

The analyses for this study compare outcomes for students in treatment schools with their counterparts in control schools at the end of grade 8 (spring 2009) and, for AR students only, at the end of grade 9 (spring 2010). All analyses of outcomes at the end of grade 8 were conducted separately for the AR and N-AR student samples; AR student outcomes were never compared with N-AR student outcomes.

Analyses of the algebra and general mathematics posttests used hierarchical linear modeling (Raudenbush and Bryk 2002), accounting for the nesting of students within schools and controlling for student- and school-level covariates. Results are reported both in their original metric and as effect sizes. The analyses of coursetaking sequences used hierarchical generalized linear models that assume a Bernoulli sampling distribution and logit link function (Raudenbush and Bryk 2002; McCullagh and Nelder 1998). These models, appropriate for use with binary outcomes, accounted for nesting of students within schools and included the same student- and school-level covariates as the models used for the achievement outcome measures.

Results

The results indicate that offering Algebra I as an online course to AR students is an effective way to broaden access in schools that do not typically offer Algebra I in grade 8. Taking this course significantly affected students' algebra achievement at the end of grade 8 and increased their likelihood of participating in an advanced coursetaking sequence in high school. The course had no discernible side effects on AR students' general mathematics achievement at the end of grade 8 or any negative effects on N-AR students' measured outcomes.

Primary Analyses

The results of the primary analyses indicated the following:

- Access to online Algebra I in grade 8 had a positive impact on AR students' algebra achievement at the end of grade 8. AR students in treatment schools outperformed those in control schools by approximately 5.5 scale score points (model-adjusted mean scores were 447.17 for the treatment group and 441.64 for the control group; $p = 0.001$; effect size = 0.39).

- Access to online Algebra I in grade 8 had a positive impact on AR students' high school coursetaking: AR students from treatment schools were significantly more likely to follow an advanced course sequence in high school than their peers from control schools. The average (model-predicted) probability of participating in an advanced course sequence was 0.51 for AR students from treatment schools and 0.26 for AR students from control schools—a difference of 0.25 ($p = 0.007$). These results mean that AR students from treatment schools were twice as likely to participate in an advanced course sequence than AR students from control schools.

To examine the robustness of these findings, researchers estimated models that examined different specifications or baseline covariates. The results of all of the sensitivity analyses were consistent with the main analyses reported. However, for both outcomes (algebra scores at the end of grade 8 and high school coursetaking), the magnitude of the impact estimate was attenuated when the Promise Assessment general mathematics pretest administered for the study was used as the baseline measure of prior achievement instead of the state mathematics assessment scores. For algebra scores at the end of grade 8, the effect of online Algebra I was still statistically significant (effect size = 0.29, $p = 0.009$); for high school coursetaking, the difference in the probability of participating in an advanced course sequence between treatment and control students fell below the level of statistical significance ($p = 0.037$).⁵

Secondary Analyses

The results of the secondary analyses indicated the following:

- AR students' general mathematics achievement at the end of grade 8 did not appear to be affected by the online Algebra I course. Model-adjusted mean scores were 361.42 for the treatment group and 357.82 for the control group ($p = 0.204$; effect size = 0.14).
- N-AR students did not appear to be affected by their schools' adoption of the online Algebra I course (offered to their AR peers) on any of the measured outcomes (algebra posttest: $p = 0.443$, effect size = 0.06; general mathematics posttest: $p = 0.789$, effect size = 0.02; planned grade 9 coursetaking: $p = .099$, difference in predicted probability = 0.10, in favor of students from treatment schools).

All sensitivity analyses testing the robustness of the secondary analyses confirmed the results reported in the main analysis, with one exception. In Model E.22, which used complete case analysis instead of multiple imputation for missing data, the difference in predicted probability of enrolling in an intermediate course sequence reached the level of statistical significance, indicating that N-AR students in treatment schools were more likely than those in control schools to enroll in an intermediate course sequence in grade 9. Nevertheless, all of the main and sensitivity analyses indicated that the offering of the online course to AR students did not have deleterious effects on AR students' general mathematics scores or on any of the measured N-AR student achievement and coursetaking outcomes.

⁵ The coursetaking result is not statistically significant after adjusting the alpha level for multiple comparisons for the two primary outcomes. The adjusted alpha level applied to both primary analyses was 0.025.

Exploratory Analyses

Two sets of exploratory analyses examined AR students' high school coursetaking more closely. First, researchers examined the effect of online Algebra I in grade 8 on the likelihood of planned enrollment in an advanced grade 9 course, as of the end of grade 8. Like the main analyses, which focused on coursetaking after a full year of high school, this exploratory analysis showed that, at the end of grade 8, AR students from treatment schools were 3.38 times more likely to enroll in an advanced course (that is, a course above Algebra I) than were AR students from control schools ($p = 0.005$).

Second, researchers used the follow-up data collected from high schools at the end of grade 9 to examine the course progressions through which AR students either met or did not meet the criteria for an advanced course sequence. The evidence indicated that 21% of the AR sample (96 students) took more than one full-year mathematics course in grade 9, planned to do so in grade 10, or both.

An exploratory impact analysis tested the effect of access to online Algebra I in grade 8 on the likelihood that AR students “doubled up” (that is, took more than one mathematics course at a time) in grade 9 or 10. The results indicated that students in control schools (predicted probability = 0.23) were more than twice as likely to double up in mathematics courses in grade 9 or grade 10 than AR students in treatment schools (predicted probability = 0.10) ($p = 0.033$). This suggests that in addition to affecting *whether* students pursue an advanced sequence, the intervention had an impact on *how* students enter an advanced course pathway. High-achieving students without access to Algebra I in grade 8 may get themselves on track for an advanced course sequence by taking two mathematics courses at a time. The study results show that access to online Algebra I in grade 8 can reduce the need to double up, allowing students who would otherwise have done so to take other high school courses and focus on one mathematics content area at a time.

Limitations of the Study and Future Research Directions

This study was conducted with a sample of schools in Maine and Vermont that met the eligibility criteria for participation and agreed to take part in a random assignment study. Many of these schools were small (48% had grade 8 enrollments of less than 17 students), and 90% were in rural areas. Analyses of longitudinal data from the ECLS-K study (U.S. Department of Education 2009) indicate that a significant proportion of schools do not offer Algebra I to grade 8 students (approximately 16% nationally), and moreover, that the proportion of schools in rural areas with limited access to Algebra I is higher than in urban and suburban areas. Still, it is not clear whether the study schools represent small rural schools located in other parts of the region or country or the extent to which the results observed in these schools generalize to other schools interested in using online courses to expand access to Algebra I to grade 8 students.

Although the consent rates and response rates were high (above 95% in the AR sample and above 85% in the N-AR sample), they were not 100%. Multiple imputation was used to adjust for any bias nonresponse might introduce, but it is not impossible that bias was nonetheless present.

The online course chosen, Class.com's Algebra I course, is similar in content and focus to the offerings of other providers. However, it is not clear that similar results would have been observed had another course provider been chosen. Moreover, the results observed in this study cannot necessarily be generalized to more recently developed online courses.

For all these reasons, replication of this study is necessary to gain a better understanding of the potential impacts of using an online course to expand access to Algebra I to grade 8 students. In particular, future studies should examine longer-term effects of access to online Algebra I in grade 8—through high school, college, and even beyond. This study included a one-year follow-up to track students from grade 8 into high school. A longer study is needed to assess whether access to online Algebra I in grade 8 continues to impact participation in advanced mathematics course sequences through the end of high school.

As the use of online courses continues to rise in U.S. schools, future research should continue to study their short- and long-term effects on student coursetaking patterns and achievement in key content areas. Further investigation of the effectiveness of online courses should contrast the offering of them with various relevant business-as-usual situations. These include school settings where students' lack of access to specific courses (where the control group does not take the course) as well as school settings where particular courses are oversubscribed or taught by under-qualified or uncertified teachers (where the control group would take a standard face-to-face version of the online course).

Schools around the country, particularly those in rural areas, are in search of innovative ways to expand their course offerings. To address this need, this study focused on the use of an online course to provide access to Algebra I in schools that do not typically offer the course in grade 8. It did not compare the effects of taking online Algebra I versus a standard face-to-face version of the course in grade 8, and the results should not be interpreted to indicate that offering online Algebra I is better than (or as good as) offering a face-to-face Algebra I course to eighth graders. In addition, given that the study compared the offering of an online Algebra I course to a lack of (or limited) access to Algebra I in grade 8, it is not possible to isolate the portion of the observed effects that is due to the fact that the course was online. The content of the course (Algebra I) cannot be untangled from the mode of instruction (online). Thus it is possible that broadening access to any type of formal Algebra I course to AR grade 8 students would yield similar effects.

Conclusions

This study is the first of its kind to rigorously evaluate the impact of offering an online version of Algebra I in schools that otherwise do not typically offer the course, even though they have students who are ready to take it. For educators and students facing similar challenges, the results of this study may be particularly informative and promising. Results showed that offering an online course to AR students is an effective way to broaden access to Algebra I in grade 8 and later, to more challenging mathematics course opportunities. The study demonstrates that an online course as implemented is more effective in promoting students' success in mathematics than existing practices in these schools.

Chapter 1 Introduction and Study Overview

A 2008 report by the National Mathematics Advisory Panel recommended that “all prepared students [should] have access to an authentic algebra course—and [that districts] should prepare more students than at present to enroll in such a course by Grade 8” (National Mathematics Advisory Panel 2008, p. 23).⁶ This recommendation echoed one made by the U.S. Department of Education (1997), which asserted that all states should invest in expanding access to Algebra I for middle school students.

Both of these policy statements are built on mainly correlational research showing that Algebra I operates as a gateway to more advanced mathematics courses in high school and college and that students who succeed in Algebra I in middle school have more success in mathematics throughout high school and college. For example, Stevenson, Schiller, and Schneider (1994) found that grade 8 students who take Algebra I are more likely than their peers to take advanced mathematics courses in high school. Smith (1996), using a large nationally representative dataset and controlling for student background characteristics, found that providing access to Algebra I in grade 8 has a sustained, positive relationship with students’ high school mathematics attainment and achievement. Spielhagen (2006) concluded that students who take Algebra I in grade 8 take more advanced mathematics courses in high school and attend college at higher rates than students with similar academic backgrounds who take Algebra I in high school. More recent analyses of high school transcript data indicate that almost two-thirds of students who took Pre-calculus or higher by the time they graduated from high school in 2009 had taken Algebra I by the eighth grade (Nord et al. 2011).

The federal policy recommendations and state and district initiatives that followed the earlier studies may have affected grade 8 Algebra I enrollments throughout the country over the past two decades. In the 1990s, 16% of grade 8 students were enrolled in Algebra I nationwide; by 2007 this figure had risen to 31% (Loveless 2008). A U.S. Department of Education report on grade 8 algebra, using data from the Early Childhood Longitudinal Study (ECLS-K), reports similar statistics. In the 2006/07 school year, 33% of grade 8 students in the national sample were enrolled in Algebra I (another 6% were enrolled in courses above Algebra I); in general, students with higher levels of prior achievement (as measured by the ECLS-K mathematics achievement test taken at the end of grade 5) were more likely to be enrolled in Algebra I in grade 8 (Walston and Carlivati McCarroll 2010).

Despite this increased enrollment trend, not all high-achieving students have the opportunity to take Algebra I in grade 8. Walston and Carlivati McCarroll (2010) found that approximately 25% of students who scored in the highest quartile on the ECLS-K grade 5 mathematics assessment were not enrolled in a formal Algebra I course in grade 8.

Additional analysis of ECLS-K data indicated that this finding is particularly pronounced in rural schools. In rural schools, 39% of high-achieving students (that is, students who scored in the top quartile in grade 5) did not take Algebra I (or higher) in grade 8. This is significantly higher than the proportion of high-achieving students in urban or suburban schools who did not take the

⁶ An “authentic” algebra course is one that covers symbols and expressions, linear equations, quadratic equations, functions, the algebra of polynomials, and combinatorics/finite probability.

course (26.4% and 26.3%, respectively).⁷ Furthermore, an analysis of school-level administrator data from the ECLS-K indicates that while nationally, 16% of schools do not offer Algebra I to grade 8 students, the rates are highest in rural schools. About 24% of rural schools do not offer Algebra I in grade 8, compared with 21% of urban schools and 9% of suburban schools.⁸

In such schools, curriculum offerings may be limited by constraints such as staffing, space, and enrollments—issues that are particularly challenging in small or rural schools, where student populations are low and attracting qualified and experienced teachers is difficult (Hammer et al. 2005; Jimerson 2006). As technology capacity increases in schools around the country, online courses are increasingly seen as a viable means for expanding curricular offerings and broadening access to key courses, especially small and rural schools (Hanum et al. 2009; Picciano and Seaman 2009; Schwartzbeck et al. 2003).

This study was conducted by the Regional Educational Laboratory—Northeast and Islands (REL–NEI). It focused on broadening access by offering an online course to grade 8 students considered by their schools to be ready for a formal Algebra I course but who would not typically take one until high school because they attend middle schools that do not offer the course.

The primary goal of this study was to determine whether broadening access to Algebra I in grade 8 by offering an online course improves students’ knowledge of algebra in the short term, opens doors to more advanced course sequences in the longer term, or both.

The secondary goal was to estimate potential unintended consequences (side effects) of offering online Algebra I to students considered algebra ready by their schools. Offering an online Algebra I course may affect students who take the course in unintended ways—by, for example, affecting their general mathematics achievement. Offering an online course may also have unintended consequences on the grade 8 students in the school who remain in the general mathematics course—through, for example, peer effects, changes in course emphasis, or smaller class sizes.

This study was designed to assess the effects—positive and negative—on all grade 8 students of offering an online Algebra I course. It sought to produce useful information for education decision makers considering investing in an online course as a means of broadening access to Algebra I in grade 8.

⁷ REL-NEI researchers conducted this analysis with the child-level ECLS-K K-8 Full Sample Public-use Data File (U.S. Department of Education 2009a). The ECLS-K study collected data from 8,703 students when they were in grade 8. After classifying the students as high achievers (based on their grade 5 assessment scores) and whether (or not) they reported taking a grade 8 mathematics course at or above Algebra I, the researchers used a Chi-square test to examine whether the proportion of high-achievers who did not take Algebra I (or higher) was different by locale (small town/rural vs. large/mid-sized city vs. suburban/large town). The difference in proportions was statistically significant, $\chi^2 = 19.4$, $df = 2$, $p < 0.001$.

⁸ Administrators of schools attended by ECLS-K student participants reported the proportion of their grade 8 students taking different mathematics courses. These data are available for 1,946 public schools. REL-NEI researchers classified schools as either offering Algebra I to grade 8 students or not, and used a Chi-square test to examine whether the proportion of schools that did not offer Algebra I differed by locale. The difference was statistically significant, $\chi^2 = 49.3$, $df = 2$, $p < 0.001$.

Significance of Algebra I

Algebra I is a gatekeeper course because it is a prerequisite for the high school mathematics and science courses considered essential, if not required, for getting into college. High school mathematics courses are ordered sequentially; students must successfully complete Algebra I before taking subsequent mathematics courses (Smith 1996; Wagner and Kieran 1989). If students succeed in Algebra I, they typically take Geometry, Algebra II, and then more advanced courses, such as Trigonometry, Pre-calculus, and Calculus.⁹ Several research studies have shown that success in Algebra I is highly correlated with enrollment in more advanced mathematics and science courses (Lacampagne, Blair, and Kaput 1995; Atanda 1999; Kilpatrick, Swoffard, and Findell 2001; Nord et. al, 2011).

Previous research, mainly correlational, suggests that having access to Algebra I in grade 8 benefits at least some students. Using data from the 1988 National Educational Longitudinal Study, Stevenson, Schiller, and Schneider (1994) examined the relationship between students' mathematics and science opportunities in grade 8 and their later opportunities in mathematics and science in high school (see also Schneider, Swanson, and Riegle-Crumb 1998). They defined three course sequences:

- Sequence A (advanced): Completion of both Geometry and Algebra II or any higher level course by grade 10
- Sequence B (intermediate): Completion of either Geometry or Algebra II by grade 10
- Sequence C (low): Completion of neither Geometry nor Algebra II by grade 10.

According to the study, 42% of students who took Algebra I in grade 8 participated in an advanced course sequence in high school. In contrast, only 12% of students who did not take Algebra I in grade 8 participated in an advanced course sequence. The study's authors conclude that mathematics course opportunities in grade 8 are related to students' subsequent opportunities to take, and succeed in, advanced course sequences in high school. Another study using the same data found that 60% of students who took Calculus by grade 12 had taken algebra in grade 8 (U.S. Department of Education 1996).

Research also suggests that students who take Algebra I in middle school subsequently have higher mathematical skills that are sustained over time. Smith (1996) used data from the High School and Beyond study to estimate the relationship between middle school algebra and later mathematics outcomes, controlling for differences in student background (social and demographic background, aptitude, and academic emphasis or interest in mathematics). Her results suggest that early access to algebra is related to high school mathematics coursetaking behavior and achievement above and beyond these observable or measurable characteristics.

⁹ The Algebra I → Geometry → Algebra II sequence is known as the traditional mathematics coursetaking pathway (National Mathematics Advisory Panel 2008; Common Core Standards Initiative 2010). Some schools reverse the order of Algebra II and Geometry, yielding an Algebra I → Algebra II → Geometry sequence; this ordering is less common than the traditional sequence. Other schools offer an integrated course pathway that combines the content of Algebra I, Geometry, and Algebra II into integrated courses, which typically have generic names, such as Mathematics 1, Mathematics 2, and Mathematics 3 (National Mathematics Advisory Panel 2008; Common Core Standards Initiative 2010).

Students who took Algebra I in middle school completed an average of one more year of mathematics courses than students who took Algebra I in high school (2.3 versus 1.3 years). They also outscored their counterparts who took Algebra I in high school on the High School and Beyond mathematics assessment in both grades 10 and 12. The differences in these outcomes were statistically significant ($p < 0.001$), controlling for students' background characteristics (Smith 1996).

Spielhagen (2006) used data from a large urban district to compare high school and college outcomes of students with and without access to Algebra I in grade 8. She concluded that grade 8 students with similar academic abilities who were provided access to Algebra I followed a more advanced coursetaking sequence in high school than students who took Algebra I in grade 9. Specifically, 82% of students who completed Algebra I in grade 8 were enrolled in a course above Algebra II in grade 11, compared with just 2% of their peers who did not complete Algebra I in grade 8. Students who completed Algebra I in grade 8 were also more likely to attend college (62%) than students who did not have access to Algebra I in grade 8 (31%).

Other research indicates that advanced coursetaking in high school (typically defined as completing courses above Algebra II) is related to the likelihood of enrolling in and completing college. Horn and Nuñez (2000) found that three-quarters of students who participated in an advanced coursetaking sequence in high school enrolled in four-year colleges. Adelman (1999, 2006) found that the odds of completing college are twice as high for students who take a sequence of advanced mathematics courses in high school. Enrollment in higher-level mathematics and science courses is also related to future educational and employment opportunities (Gamoran and Hannigan 2000; U.S. Department of Education 1997). Rose and Betts (2001) showed that students who take higher-level mathematics classes in high school have higher earnings 10 years after high school graduation, even after controlling for background characteristics and eventual educational attainment (see also Jabon et al. 2010).

Policy statements emphasizing the importance of offering Algebra I in middle school (for example, U.S. Department of Education 1997; National Council of Teachers of Mathematics 2000) have suggested that improving student performance in mathematics in high school and college requires ensuring that more students are prepared during their middle grade years to move successfully through upper-level mathematics courses in high school. In addition to expanding access to a formal Algebra I course in grade 8, these policy recommendations have likely influenced the degree to which algebraic concepts are infused into general middle school mathematics curricula and standards. For example, the National Council of Teachers of Mathematics has an algebra strand in its middle school content standards, and these standards are often reflected in middle school mathematics textbooks and state standards (National Council of Teachers of Mathematics 2000, 2006).

It is important to note that the research documenting the relationships between taking Algebra I in grade 8 and high school coursetaking and between high school coursetaking and postsecondary outcomes is mainly correlational. As such, it is subject to problems of self- and school selection of students into the course and subsequently into more advanced courses (Loveless 2008). None of the research studies to date used a random assignment design to establish statistically equivalent groups of students who do and do not take Algebra I in grade 8. This study, therefore, is the first to rigorously test the impact of providing access to Algebra I in

grade 8, to students considered ready for the course. More specifically, and as described in the following sections, the study focused on providing access by offering an online course.

The Use of Online Courses to Broaden Access

In schools that do not offer particular classes because of a lack of resources such as space and available teachers, online courses are one way to provide courses to interested or eligible students. Offering coursework virtually is a strategy that schools use to expand the curricula available to their students (National Education Association 2006), particularly in small schools and isolated communities that do not have access to critical courses in science, technology, engineering, and mathematics (Picciano and Seaman 2009; Tucker 2007).

The increasing popularity of online courses is driven by both technological advancements and the flexibility with which online courses can provide access to content and instruction (U.S. Department of Education 2009). Online courses allow schools to take advantage of a broader pool of qualified teachers, which can enable students to take courses that are otherwise not offered or taught by qualified teachers.

The use of online courses in K–12 settings has been on the rise over the past decade. According to the National Center for Education Statistics, 37% of school districts used technology-based distance learning during 2004/05 (Zandberg and Lewis 2008). In 2007/08, a national survey of K–12 public school districts conducted by the Sloan Consortium found that 75% of school districts had one or more students enrolled in online courses and that the total number of K–12 public school students engaged in online courses exceeded 1 million—a 43% increase from the 700,000 students reported in 2005/06 (Picciano and Seaman 2007, 2009). As of 2007, 28 states had virtual high school programs, enabling students to take online courses in addition to their school-based courses to fill curriculum gaps (for example, Advanced Placement [AP] courses) or providing opportunities for credit recovery (Tucker 2007).

Surveys of K–12 public schools have suggested that rural districts and schools are especially interested in online learning. In the Sloan Consortium surveys, respondents from small rural school districts reported that they use online courses to provide opportunities they would not otherwise be able to offer (Picciano and Seaman 2009).

Two other surveys examined the prevalence of rural schools' use of distance learning, a broader category that overlaps with online learning. Among the 896 superintendents of rural school districts interviewed by Schwartzbeck et al. (2003), 62% used distance learning to offer additional courses, with mathematics courses making up 22% of their distance learning offerings. In another nationally representative sample of 417 rural school districts, 85% reported having used some form of distance education at some time, with 69% reporting that they were currently doing so; of those currently using distance education, 89% reported that they needed distance education to offer advanced or enrichment courses (Hanum et al. 2009).

Of the 68 schools participating in this study, 61 are rural, as defined by the Common Core of Data. According to a 2007 report by the Rural School and Community Trust Policy Program, Maine has the highest percentage of students attending rural schools of any state in the country (52.9%), and Vermont has the second-highest percentage (51.3%) (Johnson and Strange 2007).

Thus, this study context was an ideal setting for examining the effectiveness of using an online course to expand access to Algebra I for grade 8 students.

Research on the Effectiveness of Online Courses

No rigorous studies have tested the efficacy of using online courses to broaden access to courses students could not otherwise take. Studies of virtual course programs show promising completion rates and satisfaction among students, teachers, and administrators (Optimal Performance 2006), but studies have not indicated whether online courses benefit students who would not otherwise have had access to such course subjects. This study addresses this gap.

A small body of literature compares online learning with traditional face-to-face learning, particularly at the postsecondary level. Though this study was not designed to compare online Algebra I to face-to-face Algebra I, this literature is relevant to this study because it provides information on the utility of online courses as an educational experience compared with traditional face-to-face coursework. A meta-analysis of 99 studies that met the authors' criteria for rigor finds that online instruction yields positive effects relative to face-to-face instruction (U.S. Department of Education 2009b).¹⁰ This finding is based almost entirely on postsecondary education.

Just 5 of the 99 studies included in the meta-analysis were conducted at the K–12 level, indicating the need for rigorous research on K–12 online learning. One of these studies (O'Dwyer, Carey, and Kleiman 2007) is particularly relevant, because it examined the effects of an online Algebra I course. In this quasi-experimental study, grades 8 and 9 students in 18 classrooms participating in the Louisiana Algebra I Online Project were compared with students in comparison classrooms on outcomes including an end-of-year Algebra I assessment. The authors compared pretest scores on a general mathematics assessment and demonstrated that the online and comparison students were not statistically different at baseline. At the end of the school year, the difference in scores between students in the two types of classrooms on an algebra posttest was not statistically significant (average scores on the 25-point test were 15.27 for the online group and 14.61 for the comparison group, $p = 0.093$). These findings provide suggestive evidence that online Algebra I can produce outcomes that are similar to the outcomes in traditional Algebra I courses. It is possible that 18 classes per group was too small a sample size to detect a true effect on the algebra posttest. Students in the online class reported feeling less confident in their algebra skills, but they outscored students in comparison classrooms on groups of items that required creating an algebraic expression from a real-world example. This study provides foundational information on potential effects of online Algebra I. The current study, while neither designed nor intended to compare the effectiveness of online vs. face-to-face Algebra I courses, builds on these findings to investigate the impact that access to an online Algebra I course has on academic outcomes for both course participants and their nonparticipating peers.

¹⁰ Studies that qualified for inclusion in the meta-analysis used an experimental or quasi-experimental design (if quasi-experimental, the study must have included statistical controls for prior achievement). They also reported data sufficient for calculating effect sizes per the What Works Clearinghouse (2007) guidelines.

Selection of the Online Course for This Study

The goal of this study was to examine the impact of offering an online Algebra I course to broaden access to grade 8 students, not to study the effectiveness of a particular course provider's online Algebra I course. In fall 2007, REL–NEI established the following criteria for selecting an online Algebra I course provider:

- The content of the Algebra I course represents what is typically part of a high school level Algebra I course.¹¹
- The course provider is established and has a widespread presence in secondary schools.
- The course provider offers courses that are geared toward a range of learners, including courses used for both remediation and acceleration (that is, it does not specialize only in AP courses).
- The course provider is willing to offer individual seats in a course for as few as one student per study school (at a competitive per student fee).
- The course provider hires, trains, and supervises the online teachers for the purpose of the study. (This criterion was considered essential given the study's focus on rural schools, which typically do not have the resources to provide an Algebra I teacher or course to their grade 8 students.)
- The provider is willing to participate in a randomized study and operate within the study's parameters.¹²

The study team identified potential course providers by conducting Internet searches, reviewing the providers listed in the National Repository of Online Courses, and contacting course providers known to REL–NEI from previous research projects.¹³ It identified 11 online course providers that offered an Algebra I course. After reviewing the online course providers, REL–NEI determined that all 11 providers met the first two criteria and reached out to all of them. REL–NEI contacted each organization at least three times to request a conversation. Four of the 11 providers indicated initial interest. One of these providers did not want to be included in an evaluation study, one indicated that its current focus was to provide Advanced Placement courses, and a third was no longer interested once it understood the scope of the study. At the conclusion of the interviews, only the online Algebra I course provided by Class.com met all the criteria required for the study.

¹¹ See appendix C for a comparison of the learning objectives and course content of the Class.com Algebra I course and standard Algebra I courses.

¹² For example, the provider needed to be able to implement the program in the fall without knowing the number of students who would be enrolled until the summer before implementation and to structure online sections that encompassed a variety of schools, schedules, and calendars.

¹³ Terms used in the Internet search included “online course providers,” “online courses,” “algebra online,” “algebra AND online,” “virtual school,” “virtual school algebra,” “algebra I online,” “distance education,” and “distance education AND algebra.”

Overview of the Class.com Online Algebra I Course

The Class.com course content was originally developed by teams from the University of Nebraska, funded by a 1996 U.S. Department of Education Star Schools grant. Class.com was created to make these courses available on an ongoing basis. It has been a self-sustaining business since 1999. Class.com is a privately held small business that partners with more than 4,400 secondary schools across the country. At the time of selection, its courses were determined to meet the guidelines of the Southern Regional Education Board's *Essential Elements for Web-Based Courses for High School Students* (Thomas 1999), which was widely used as the benchmark for quality assurance by states for online education.¹⁴

Class.com had not delivered its Algebra I course to middle school students before the study. It assumed that AR students would be ready for a high school version of Algebra I and therefore did not reduce the academic rigor for delivery in grade 8.

Like online classes offered by other providers, Class.com classes contain many of the same instructional components as a traditional face-to-face class, including defined learning objectives, curriculum materials, assignments, problem sets, quizzes and tests, and grades. The online Algebra I course used in this study provides a structure and a schedule of requirements throughout the school year. Like traditional courses, courses are structured into major topic units and individual lessons within units. Students are expected to follow a schedule in completing each lesson and to be prepared for quizzes and tests as scheduled.

Online and traditional classes have many parallels but also some critical differences, particularly in the forms of communication available to students and teachers. In the Class.com online Algebra I course, the primary form of communication is asynchronous online exchanges (that is, the student and the teacher are not online at the same time). Because the interactions are online, class participants do not need to gather in one place and can be distributed in different locations. Because the interactions are asynchronous, class participants within the same section do not need to be online at the same time.

Intended Implementation of the Online Course in This Study

For AR students in treatment schools, the online Algebra I course was offered instead of regular mathematics instruction. As in a traditional class, students taking the online course were assigned to a specific section and taught by a teacher who was responsible for providing instruction and supporting their learning. Class.com recruited teachers to teach the online Algebra I course in participating schools. Their responsibilities included grading homework, monitoring student understanding, promoting student engagement, conducting online discussions, and monitoring student performance on quizzes and exams. This online course model was intended to be different from online tutor approaches, in which the primary interactions are between individual students and the computer.

¹⁴ These standards include providing instruction that engages students in activities that address various learning styles; opportunities for students to engage in abstract thinking; appropriate teacher-to-student interactions, such as feedback on student progress; opportunities for appropriate interaction among students; and assessment of students' content mastery using fair, adequate, and appropriate methods and procedures.

All schools were required to specify a class period for students take the course. However, the specified time was allowed to differ for students in the same class, students from different schools could be in the same online section, and students could access the class website at any time, in addition to the scheduled class period (although out-of-school access to the Internet was not a requirement for participating in the intervention).

All participating schools were required to provide an on-site proctor to monitor students while they were accessing the course. In addition to possessing basic computer skills, the proctor was expected to supervise students' behavior, serve as a contact for students and parents, proctor quizzes and exams, and act as a liaison between the online teacher and the school, students, and parents. The proctor was not required to provide instruction and therefore did not need to be a mathematics teacher.

Because teachers and students typically were not online at the same time, they communicated through an online course messaging system or discussion boards.¹⁵ Online teachers were encouraged to send students personal messages regarding each day's work or homework submitted the previous day and to reply to any student messages within 24 hours. (Chapter 3 provides more information on the intended implementation of the online course.)

Programmatic Features of the Intervention

The online Algebra I course is a multidimensional intervention with programmatic features that make it different from "business as usual" mathematics instruction. In addition to changing the instruction received by students taking Algebra I, offering an online algebra course may change the grade 8 mathematics program available to students not taking Algebra I. Six programmatic features of the online Algebra I course may cause changes in grade 8 mathematics:

- *Course content:* AR students in schools that offer the online course have access to a course with typical Algebra I content. In the absence of the course, AR students take a general grade 8 mathematics course whose content includes algebraic concepts but is not a formal Algebra I course.¹⁶
- *Mode of instruction:* The online Algebra I course is completely web based and has three instructional components: the online course software, the online teacher, and the on-site proctor. Regular grade 8 mathematics classes may use technology to varying degrees, but the classes are not online courses and instruction is delivered primarily face to face.
- *Teacher qualifications:* Online teachers are required to be certified and trained in both the content and the delivery mode. Not all teachers in the regular mathematics course may be certified.
- *Staffing intensity:* Adoption of the online course adds a teacher—the online teacher. Schools using the online course were also required to assign a proctor to support students

¹⁵ Students and online teachers did not use email to communicate. All communications among teachers and students occurred within the learning management system.

¹⁶ A review of the mathematics content standards in both states before this study was launched revealed that all middle school students are expected to learn algebraic content in grade 8.

taking the course. In contrast, the regular grade 8 mathematics program is staffed by the usual number of educators in schools that do not offer online Algebra I.

- *Class size:* In schools that offer the online Algebra I course, the AR students are removed from the general grade 8 mathematics class to take the online course. Therefore, N-AR students are in general mathematics classes that are smaller than they would have been without the online Algebra I course.
- *Ability grouping:* In schools that offer the online Algebra I course, higher-ability students are removed from the general grade 8 mathematics class to take the course. As a result, the remaining students are more homogenous and lower in average ability than they would have been had the online course not been offered. This change in the composition of the general mathematics class may result in changes in the content taught. For example, the course may be less challenging than it would have been or place less emphasis on algebra concepts than it would have had the AR students remained in the class. In the absence of the intervention, students are not necessarily separated into ability groups for mathematics instruction.

Given the multidimensional nature of the intervention and the research design, it is impossible to attribute impacts to these six features individually. Nevertheless, it is important to identify these features to understand the comprehensive effects that adopting such a course can have. In Chapter 3, the implementation of mathematics instruction in both treatment and control schools is described in relation to these six dimensions.

Study Purpose and Research Questions

The goal of this randomized controlled trial is to ascertain the effects of broadening access to Algebra I to grade 8 students using an online Algebra I course in schools that do not typically offer Algebra I. In particular, this study addresses the following policy question:

In schools that do not offer Algebra I to grade 8 students, what are the effects of offering Algebra I as an online course to students who are considered algebra ready?

This policy question concerns the effects on student achievement in mathematics and subsequent high school mathematics coursetaking for all grade 8 students in a school.

The primary focus was on the effects on AR students. Students were identified as AR before random assignment to ensure the comparability of students in treatment and control schools. The online course was then offered to AR students in the treatment schools.

The secondary goal of the study was to determine whether the delivery of the online course has side effects on AR students' general mathematics achievement or on outcomes for N-AR students in participating schools. Implementing the online Algebra I course required removing AR students from the regular grade 8 mathematics class. This removal may impact AR students' general mathematics scores—an effect that is important to teachers and administrators concerned with their students' individual achievement as well as their school's performance on grade 8 state mathematics assessments. The removal of AR students may also have indirect effects on N-AR students as a result of the change in class size and composition.

Primary Research Questions

The two primary research questions focus on the direct effects of broadening access to Algebra I by offering an online version of the course to AR students:

1. What is the impact of offering Algebra I online to AR students on their algebra achievement at the end of grade 8?
2. How does offering Algebra I online to AR students affect their likelihood of participating in an advanced course sequence in high school?

The direct effects of this intervention on these outcomes for AR students are of primary concern for determining whether this intervention is an effective way for schools to broaden access to Algebra I.

To test the primary research questions, the study team measured algebra achievement with a computer-adaptive assessment. It defined advanced coursetaking as completion of a grade 9 course above Algebra I; success in the grade 9 course above Algebra I (a grade of C or higher); and enrollment in the next course in the sequence in grade 10. This definition was based on research on mathematics coursetaking using national samples (Stevenson et al. 1994; Schneider et al. 1998) that defined advanced coursetaking as the completion of Algebra II by the end of grade 10. Because this study followed students only until the end of grade 9, grade 9 actual coursetaking and grade 10 planned coursetaking were used as the indicators of the likelihood of participating in an advanced sequence through high school.¹⁷

Secondary Research Questions

Four secondary research questions are designed to test whether there are significant side effects of adopting an online Algebra I course for the purpose of broadening access for AR students:

3. What is the effect of providing online Algebra I to AR students on their general mathematics achievement at the end of grade 8?
4. What is the effect of providing online Algebra I to AR students on the algebra achievement of N-AR students at the end of grade 8?
5. What is the effect of providing online Algebra I to AR students on the general mathematics achievement of N-AR students at the end of grade 8?
6. How does offering an online Algebra I course to AR students affect the likelihood that N-AR students participate in an intermediate course sequence in high school?¹⁸

To test the secondary research questions, the study team measured general mathematics and algebra achievement with a computer-adaptive assessment administered to both AR and N-AR students. It defined intermediate coursetaking as the projected completion of Algebra I in grade 9.

¹⁷ The advanced sequence reflects a traditional coursetaking sequence that goes from Algebra I to Geometry to Algebra II to Trigonometry/Precalculus to Calculus, in which each course is a prerequisite for the next. This is the sequence researchers expected to find in most high schools in Maine and Vermont. The definition was applied based on the actual course sequences in the high schools AR students attended in grade 9, as explained in chapter 2.

¹⁸ Although researchers did not follow N-AR students' coursetaking in grade 9, they did determine at the end of grade 8 whether they appeared likely to follow an intermediate high school course sequence the following fall.

Exploratory Research Questions

The study also posed two exploratory questions that further examine the impact of offering online Algebra I to AR students on their high school coursetaking patterns and progression:

7. How does access to online Algebra I in grade 8 affect the likelihood that AR students sign up for advanced courses in grade 9?
8. How does access to online Algebra I in grade 8 affect the likelihood that AR students “double up,” or take more than one mathematics course per year, in grade 9 or 10?

Overview of the Study’s Evaluation Design

This study is a randomized controlled trial with randomization at the school level. Schools in Maine and Vermont that did not offer a full section of Algebra I to grade 8 students (as of the 2007/08 school year) were eligible for the study. Sixty-eight eligible schools were randomly assigned to one of two study groups. Schools in the treatment condition received the online algebra course for the 2008/09 school year; schools in the control condition did not receive the online Algebra I course during the 2008/09 school year.¹⁹ To estimate the impacts of online Algebra I on relevant outcomes for both AR and N–AR students, researchers compared outcomes for students in treatment schools and students in control schools at the end of grade 8 (spring 2009) and (for AR students only) at the end of grade 9 (spring 2010). The observed impacts will help determine whether adopting an online Algebra I course is a good choice for schools that do not offer Algebra I to grade 8 students.

For the AR sample, this study was thus also longitudinal in design. The premise of “pushing down” Algebra I to grade 8 is that it prepares students for more rigorous coursetaking in mathematics through high school, which better prepares them to succeed in advanced course sequences that prepare them for college. Therefore, of critical interest from a policy perspective is the extent to which offering an online algebra course to students who would otherwise not have been able to take Algebra I in grade 8 has a sustained impact on their mathematics coursetaking in high school. For this reason, researchers tracked the AR students who attended participating schools into high school to collect mathematics coursetaking information (grade 9 courses and grades and grade 10 planned courses) at the end of grade 9. These data were used to categorize students as participating in an advanced mathematics course sequence in high school.

Researchers did not follow N–AR students into high school because of cost constraints (there were approximately three times as many N–AR students as AR students) and because assessing the impact of the online Algebra I course on AR students’ subsequent high school coursetaking was most critical and relevant for the study.

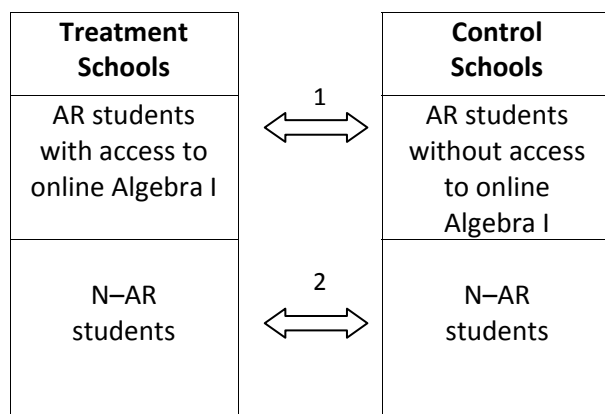
Evaluation Framework

This study compared AR students in treatment schools (who are offered the online Algebra I course) with AR students in control schools (who are not offered the online Algebra I course and presumably took a general mathematics course). The study did not make a direct contrast between online Algebra I and standard, face-to-face delivery of Algebra I. The comparison of

¹⁹ Schools in the control group received the online course for the 2009/10 school year. All schools (treatment and control) were provided the online course for two consecutive years.

AR students in treatment schools to AR students in control schools was designed to reveal the effects on students' mathematics achievement, over time, of using an online course in order to broaden access to Algebra I for students who otherwise would not have access to a formal Algebra I course. The study also compared N-AR students in treatment schools with N-AR students in control schools (figure 1-1). All N-AR students were expected to take the regular general mathematics course.

Figure 1-1. Framework for Estimating Impacts of Online Algebra I on AR and N-AR Students



Definition of a Successful Intervention

The online Algebra I course was considered successful if the results showed both

- A statistically significant positive impact on either of the two primary research questions (AR students' algebra scores at the end of grade 8 or high school coursetaking).
- The absence of statistically significant negative side effects (as assessed by the four secondary research questions).²⁰

Only this combination of results provides evidence that there are benefits of adopting an online Algebra I course for AR students without significant negative consequences to them or their N-AR peers.

Content and Organization of This Report

The findings in this report focus on the impacts of online Algebra I at the end of the school year during which the intervention was implemented (2008/09) and on coursetaking in the year following implementation. Chapter 2 describes the research design and methodology; chapter 3 describes the implementation of the intervention; chapter 4 analyzes the impacts of the intervention on short- and longer-term outcomes; chapter 5 presents exploratory analyses related to AR students' coursetaking; and chapter 6 summarizes key findings. Appendixes provide

²⁰ For the secondary questions, the study was not designed to determine whether the groups are statistically equivalent. A lack of statistical significance for an impact estimate does not mean that the impact being estimated equals zero. Rather, it means that the estimate cannot reliably be distinguished from zero, an outcome that may reflect the small magnitude of the impact estimate, the limited statistical power of the study, or both.

additional detail on the study samples, the data collected and measures used, the intervention, and the statistical estimation methods used.

Chapter 2 Study Design and Methodology

This chapter summarizes how schools were recruited and randomly assigned to condition. It describes the characteristics of the participating schools, teachers, and students at the beginning of the study. The chapter also provides an overview of the data collected from participants during the study, provides baseline comparisons of the treatment and control groups (at random assignment and at analysis), and describes the analysis of these data to address the study's research questions.

Recruitment, Random Assignment, and Study Samples

This section describes the recruitment of schools and the random assignment procedure used to allocate schools to treatment and control groups. It also describes the sample of schools and students assigned to each condition.

Recruitment of Schools

The target population included schools in Maine and Vermont that serve students in grade 8 and did not offer a stand-alone Algebra I class in 2007/08.²¹ Schools that delivered Algebra I content to some students by providing accelerated material in the context of the regular grade 8 mathematics curriculum were considered eligible for the study. These two criteria—serving grade 8 students and not offering stand-alone Algebra I—plus the willingness to comply with the requirements of the study, were the only eligibility criteria for participation.

The minimum detectable effect is the smallest true effect that has an 80% chance of being found to be statistically significant at the 5% level of statistical significance for a two-tailed test. When a minimum detectable effect is expressed in standard deviation units, it is referred to as a minimum detectable effect size. A minimum detectable effect size of 0.25 is considered necessary for the effect of an intervention to have “educational significance” (Bloom, Hill, Black, and Lipsey 2008). Power analyses indicated that a minimum of 60 schools were needed to achieve this minimum detectable effect size.²² (See appendix A for more information on the study's power analyses.)

The study was conducted in two states in the Northeast region, Maine and Vermont. Maine was chosen because in addition to relatively low overall enrollments in Algebra I among grade 8 students (20%–25% in 2007), the state has a strong technology initiative that can support the infrastructure needed to offer an online course in schools. The Maine Learning Technology Initiative provides all grade 8 students and teachers in Maine with their own laptop computer for use throughout the school year, both in and out of school. Students are thus familiar with using

²¹ A stand-alone class was defined as one full section of Algebra I taken by at least 20–25% of grade 8 students in the school, with a dedicated teacher. This proportion was derived from the percentage of grade 8 students in the REL-NEI region who took Algebra I as of 2007, which was 25% (U.S. Department of Education 2007a).

²² Based on initial power analyses, the original target number of schools to participate in the study was 40. However, initial recruitment efforts in Maine revealed that the number of grade 8 students within eligible schools was lower on average than the initial power estimates assumed (that is, the schools eligible for the study were smaller than expected). Therefore, the power calculations were revisited and the minimum number of schools was increased to 60.

computers as part of their daily educational activities (Berry and Wintle 2009; Silvernail and Gritter 2007). The technology infrastructure in Maine helps drive interest in online courses.

To identify eligible schools in Maine, researchers used the Common Core of Data to find schools that served grade 8 students during the 2007/08 school year. Initial recruitment—including determination of eligibility and interest in participation—focused on all public schools in Maine that serve grade 8 students (a total of 224 schools as of fall 2007). Initial recruitment efforts, which began in winter 2008, focused on identifying schools eligible for the study and interested in participating.

Later recruitment focused on approximately 40 schools in Vermont that state administrators and local educators thought would most likely be eligible. Recruitment was expanded to Vermont in spring 2008 because the larger sample size requirements could not be met in Maine alone. Vermont was selected because it shares demographic and geographic characteristics with Maine that were factors in the selection of Maine for the study. Specifically, Vermont has the second-highest proportion of rural schools in the United States, after Maine (Johnson and Strange 2007) and these schools serve students who, although racially and ethnically homogenous, are diverse in socioeconomic status. Like rural schools in Maine, rural schools in Vermont find it challenging to offer a full range of courses to students who might benefit from them. Although at the time of the study Vermont did not have the laptop initiative that Maine had, the state had both the necessary technological capacity and an interest in exploring ways to use technology to improve education. Initial contacts with state-level administrators and staff of the state education agency indicated a strong interest in the study, and REL–NEI has strong connections with policymakers, administrators, and mathematics educators in the state.

School recruitment for this study involved a planned sequence of outreach at the state, district, and school levels. The partnerships REL–NEI had already established in Maine and Vermont facilitated these contacts. Initial recruitment outreach began at the state level. It involved obtaining endorsements of the study from the Commissioner of Education in Maine and the Acting Commissioner in Vermont. Study leaders attended meetings with state- and district-level staff in both states to achieve buy-in for the study and gather information regarding which schools to target.

In April 2008 (the spring before implementation), the study team contacted—by phone and in person—the 224 schools in Maine that served grade 8 students to determine eligibility and assess interest in participation. Meetings were held with school principals and often included grade 8 mathematics teachers. In May 2008, when recruitment was expanded to Vermont, officials in the state department of education and local educators helped the study team identify schools they believed were most likely to meet the two eligibility requirements for the study (that is, serving grade 8 students and not offering a separate Algebra I course). An initial pool of approximately 40 Vermont schools was selected, and recruitment activities focused on these schools.

Protocols that included talking points, scripts, and a checklist of items to be addressed guided all communications with schools. Class.com, the online Algebra I course provider, provided web-based course demonstrations that allowed principals, mathematics educators, school technologists, parents, and community members to see the course and ask questions about it or the research study. Class.com staff members were also available for briefings and question and

answer sessions with state- and district-level mathematics supervisors and policymakers, including the REL–NEI governing board.

During recruitment, the study team informed schools of the requirements they would have to meet if they were randomized to the treatment group. First, students taking the online Algebra I course would take the course as their grade 8 mathematics course, not as a supplemental course to the general grade 8 mathematics class. Second, each participating student would have access at school to a computer with a high-speed Internet connection. Access to a computer was necessary for students to access the course and communicate with the online teacher.²³ Third, schools were required to assign a class period during the school day during which students would access the online Algebra I. The online class had to occur with the same frequency and duration as the regular grade 8 mathematics classes, but schools could schedule the period whenever they wanted, create multiple periods during the school day, and determine the location of the online course (for example, the regular classroom or the library). Fourth, schools would provide a staff member to serve as an on-site proctor to support the students taking the online course.

Schools signed memoranda of understanding to signal their agreement with the requirements of participation in the study. The terms and conditions of the memorandum of understanding included clear information on random assignment. Moreover, all schools were required to provide a list of AR students who would be eligible for the intervention should the school be assigned to receive the course during the 2008/09 school year. This requirement ensured that schools' identification of AR students was unaffected by their assignment to the treatment or control group.

By mid-June 2008, 71 schools in Maine and Vermont signed memoranda of understanding indicating their interest in participating in the study. Among the schools that agreed to participate, three schools withdrew from the study before or after random assignment. Reasons for withdrawal included lack of identification of AR students before random assignment and principal turnover. Following these exclusions, 68 eligible schools were randomly assigned to a condition and participated in the study.

Description of Participating Schools

The 68 schools that were randomly assigned are spread across Maine and Vermont. Sixty-two are rural schools, as defined by the Common Core of Data. As of the 2007/08 school year, grade 8 enrollments ranged from fewer than 4 to nearly 150 students, with an average enrollment of 32 students. Fifty-two schools (76%) served grades pre-K–8 or K–8; 10 schools (14%) served middle grades (grades 5–8, 6–8, or 7–8); and the remaining six schools serve other grade spans including K–12, 7–12, and 3–8.

To take the online course, students were expected to have been deemed “algebra ready” before random assignment (that is, as of the end of grade 7). AR students were students whom teachers, principals, and guidance counselors perceived as having the requisite skills at the end of grade 7 to take Algebra I in grade 8. Schools made decisions about which students were ready for algebra on the basis of teacher perceptions of preparedness; grades in mathematics classes

²³ Technology requirements and system specifications were provided to all schools during recruitment and again to the schools in the treatment group before the beginning of the 2008–09 school year.

through grade 7; scores on state assessments; and scores on other assessments, such as algebra readiness tests. The research team did not impose a definition or set of criteria for “algebra readiness” on the participating schools for two main reasons. First, there were no common instruments across all schools that were administered prior to random assignment that were specifically measures of algebra readiness. Second, the study aimed to test the effectiveness of offering an online Algebra I course in a real-world context, where local decisionmaking about student eligibility for the course would be the norm.²⁴

Before random assignment, the 68 schools allocated to treatment or control groups identified 468 AR students, an average of 6.9 students per school. These students represented 23% of the rising grade 8 students in participating schools as of spring 2008.

Random Assignment Procedure

The schools were stratified by two blocking variables: state and school size. The blocking variables were selected with the expectation that the variability across schools would be smaller within state and size blocks than in the full sample. The state blocks had two categories: Maine and Vermont. The size block had three levels, based on the size of the entering grade 8 student population: small (fewer than 17 grade 8 students), medium (17–70 grade 8 students), and large (more than 70 grade 8 students). Half of the schools within each state by size block were randomly assigned to the treatment group (table 2-1).²⁵

Table 2-1. Number of Treatment and Control Schools, by Enrollment Size

Block	State	Size (based on grade 8 student population)	Number of treatment schools	Number of control schools	Total number of schools
1	Maine	Small (fewer than 17)	12	12	24
2 and 3	Maine	Medium (17–70) and large (71 or more)	13	13	26
4	Vermont	Small (fewer than 17)	5	3	8
5 and 6	Vermont	Medium (17–70) and large (more than 70)	5	5	10
Total			35	33	68

Note: Sample included 68 schools (35 treatment, 33 control). To maintain the confidentiality of participating schools, researchers aggregated blocks that included fewer than three schools for presentation purposes only.

Source: Study records.

²⁴ Because schools used their own criteria for identifying AR students, it is possible that the AR and N–AR student samples would not have been distinct in terms of prior achievement, as intended. The differences at baseline between the AR and N–AR samples are presented in a section below on Sample Characteristics at Random Assignment. (Details on differences between the AR and N–AR samples are also provided in appendix A.)

²⁵ When the number of schools within a block was odd, a coin was flipped to determine whether the last school would be assigned to the treatment or control group.

Participating schools were informed of their treatment or control status in late June 2008. Schools that were randomized to the treatment group were informed that their AR students would have the option to take the online Algebra I course during the 2008/09 school year. Schools randomized to the control group were informed that their school would conduct business as usual during the 2008/09 school year. All 68 schools cooperated with data collection and fully participated in the study during the 2008/09 school year. This participation included implementation of the online Algebra I intervention in all 35 schools that were randomized to the treatment condition.

Student Samples

The study included two samples of grade 8 students: AR students and N-AR students (table 2-2). At the start of the 2008/09 school year, 445 AR students were enrolled in the 68 schools randomly assigned to either treatment or control, because 23 AR students had moved over the summer (12 from treatment schools and 11 from control schools). The average number of AR students per school was 6.5. AR students represented 22% of grade 8 students in participating schools. In four small schools, all grade 8 students were identified as AR students.

N-AR students were identified by collecting rosters of grade 8 mathematics classes from all study schools at the start of the 2008/09 school year. The sample included 1,554 students enrolled in study schools at that time. Students who arrived in the study schools after the start of the school year (that is, after pretesting was complete) were excluded from the analysis.

Table 2-2. Number of Schools and Students per Condition as of Fall 2008

Item	Total	Treatment	Control	<i>p</i>-value
Number of schools	68	35	33	a
Number of grade 8 AR students	445	218	227	0.670
Number of grade 8 N-AR students	1,554	782	772	0.800
Total number of grade 8 students	1,999	1,000	999	0.982
Average number of AR students per school (standard deviation)	6.54 (5.23)	6.23 (5.21)	6.73 (5.32)	0.698
Average number of grade 8 students per school (standard deviation)	31.94 (37.01)	31.00 (40.93)	32.94 (32.96)	0.830

AR is algebra ready. N-AR is not algebra ready.

Note: Sample includes 68 schools (35 treatment, 33 control) and 1,999 students (445 AR students, 1,554 N-AR students). AR students were identified before random assignment in June 2008. The sample of AR students does not include 23 students who moved during summer 2008; it does include 5 students who later refused to participate in the study. The number of N-AR students is based on information obtained from school rosters in fall 2008. The N-AR sample includes 63 students who later refused to participate in the study and 46 students who were later deemed “not testable” by their teachers and schools. Tests of significance were conducted using two-tailed χ^2 and independent sample *t*-tests.

a. Not applicable, because schools were allocated to treatment and control using a block randomized procedure.

Source: Records obtained from each school before random assignment (June 2008) and school rosters examined in fall 2008.

Enrollment in the Online Course

More than 96% of the AR students in treatment schools (211 of 218) enrolled in the online Algebra I course for the 2008/09 school year (table 2-3). In control schools, none of the 227 AR students enrolled in the online Algebra I course, which was not offered at their schools. There

were no student crossovers (AR students from control schools who moved to a treatment school and enrolled in the course).

Of the 782 N-AR students in treatment schools, 31 enrolled in the Algebra I online course.²⁶ The remaining N-AR students in treatment schools, and all of the 772 N-AR students in control schools, did not enroll in the course.

Table 2-3. Allocation of Students in Treatment and Control Schools, as of Fall 2008

Type of student	Number of students in treatment schools	Number of students in control schools
AR	218	227
Enrolled in the online course	211	0
Not enrolled in the online course	7	227
N-AR	782	772
Enrolled in the online course	31	0
Not enrolled in the online course	751	772
Total grade 8 students	1,000	999

AR is algebra ready. N-AR is not algebra ready.

Note: Sample includes 68 schools (35 treatment, 33 control) and 1,999 students (445 AR students, 1,554 N-AR students). The sample of AR students does not include 23 students who moved during summer 2008; it does include 5 students who later refused to participate in the study. The N-AR sample includes 63 students who later refused to participate in the study and 46 students who were later deemed “not testable” by their teachers and schools. Students who moved into study schools during the 2008/09 school year were deemed ineligible because they were not classified as algebra ready or not algebra ready before random assignment.

Source: Records obtained from each school before random assignment (June 2008) and school rosters examined in fall 2008.

Consent

At the beginning of the 2008/09 school year, information on the study was sent home to parents of all grade 8 students in the schools, with a form to complete if parents wanted to withdraw their children from participating in data collection activities. Sixty-eight students were withdrawn from data collection (29 N-AR students in treatment schools and 5 AR students and 34 N-AR students in control schools; see table 2-4).

Table 2-4. Students Not Granted Parental Permission to Participate in the Study

Type of student	Treatment		Control		<i>p</i> -value
	Number	Percent	Number	Percent	
AR (<i>n</i> = 445)	0	0	5	2.2	0.144
N-AR (<i>n</i> = 1,554)	29	3.7	34	4.4	0.455

AR is algebra ready. N-AR is not algebra ready.

Note: Tests of significance were conducted using hierarchical linear models that adjusted for the nesting of students within schools.

Source: Study records.

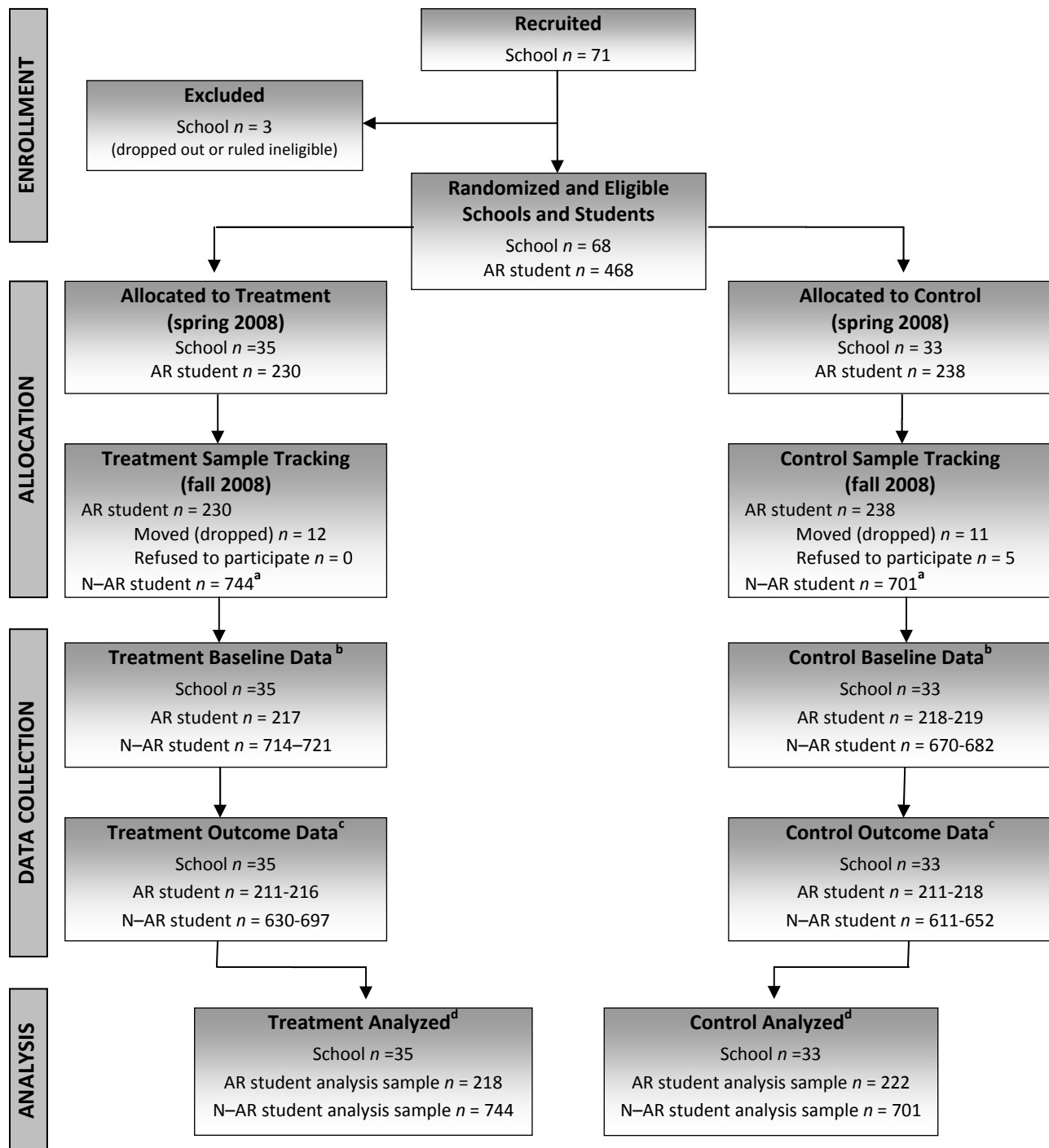
²⁶ Schools were allowed to enroll additional students in the online course. The 31 N-AR students who enrolled in the online course did so because their teachers, their parents, or the students themselves believed that the course was appropriate for them, even though they were not initially considered algebra ready when schools were asked to submit their lists. Although these students participated in the intervention, they are not part of the AR student sample and remain in the non-algebra ready student sample for analysis.

In preparation for administration of the pretest, a second set of students was withdrawn from data collection. These students were deemed “not testable” by their schools and teachers, because given these students’ special education status, appropriate accommodations could not be provided for the pretest and posttest administered as part of the study. All “not testable” students were in the N–AR student sample (9 in treatment schools, 37 in control schools). Like the students whose parents withdrew them from data collection, they are considered out of scope of the analytic sample.

For the 2009/10 follow-up data collection of high school course information for the AR student sample, 10 of 66 high schools required additional consent from parents to release student data. In these schools, one of the following consent procedures was used: the study team worked with the schools to obtain written documentation of consent, the study team sent additional information home to parents with a form to complete if parents wanted to opt out, or the principal contacted parents informally to ask for permission to participate.

Figure 2-1 presents the study sample through the study, from recruitment to analysis. (See appendix A for detailed information on the sample).

Figure 2-1. Consolidated Standards of Reporting Trials (CONSORT) Diagram



a. The N-AR sample was 1,554 students. However, due to the withdrawal of students from data collection by parents ($n = 63$) and schools ($n = 46$), the total N-AR student sample allocated to treatment and control was 1,445 with 744 students allocated to treatment and 701 students allocated to control.

b. The reported ranges for the baseline sample sizes are the ranges of nonmissing data for the two baseline measures, state mathematics assessments and the study-administered general mathematics pretest. Study-

administered pretest scores that were based on testing time of less than five minutes were excluded from the sample size ranges.

c. The sample size ranges reported for the outcome data are the ranges of nonmissing data for the three outcome measures (the end of grade 8 algebra posttest, the planned grade 9 courses, and high school coursetaking information [collected for AR students only]). Posttest scores that were based on testing time of less than five minutes were excluded from the sample size ranges.

d. Multiple imputation was used for data analysis. The number of imputed cases ranged from fewer than 4 to 7 for the AR treatment sample, depending on the outcome, and from 47 to 114 for the N-AR treatment sample, depending on the outcome. The number of imputed cases was 4–11 for the AR control sample, depending on the outcome, and 49–90 for the N-AR control sample, depending on the outcome.

Source: Study records.

Data Collected for the Study

The study data serve four main purposes. They document the implementation of the online Algebra I course and the general mathematics course in comparison schools, provide descriptive information on sample characteristics, provide covariates for the outcome analyses, and serve as the study outcomes. This section briefly overviews the data collected (appendix B provides more detailed information on the measures used). Table 2-5 lists the main sources of data for the study and the timeline for data collection.

Table 2-5. Data Sources and Collection Schedule

Type of data	Primary purpose			Data collection schedule						
				Preintervention	Intervention			Postintervention		
	Sample characteristics/ covariates	Document implementation	Measure outcomes	Spring 2008	Fall 2008	Winter 2009	Spring 2009	Fall 2009	Winter 2010	Spring 2010
School characteristics	✓			✓						
Student characteristics	✓			✓						
State assessment scores (prior mathematics achievement)	✓			✓						
Study-administered pretest (general mathematics)	✓				✓					
Site visits		✓			✓	✓	✓			
Online course activity data		✓			✓	✓	✓			
Proctor logs		✓			✓	✓	✓			
Teacher survey	✓	✓					✓			
Classroom materials		✓					✓			
Study-administered posttests (Algebra I and general mathematics)			✓				✓			
Planned grade 9 mathematics courses			✓				✓			
High school characteristics and course offerings	✓							✓	✓	✓
Grade 9 course types and grades (AR students only)			✓							✓
Planned grade 10 mathematics courses (AR only students)			✓							✓

AR is algebra ready.

Measures of Sample Characteristics and Covariates

- **School characteristics**

- *Middle schools.* Researchers obtained demographic characteristics of the participating schools—including total enrollment, the demographic composition of the student body, the percentage of students eligible for free or reduced-price lunch, Title I status, and grade span for the year before the study—from the Common Core of Data. These data were used in a baseline (preintervention) comparison of schools in the treatment and control groups.
- *High schools.* Data were also collected on the 66 high schools that AR students attended in 2009/10 as grade 9 students. Forty-five of these high schools were public and 21 were private. Data on public high schools were collected through the Common Core of Data for 2007/08. Data on private high schools were collected through the Private School Universe Survey for 2007/08.

- **Student characteristics.** Administrative records for all grade 8 students in the study were obtained from the Maine State Department of Education for students in Maine and from each supervisory union (district) for students in Vermont. Data collected included race and ethnicity, gender, eligibility for free or reduced-price lunch, and eligibility for special education services. Student-level demographic characteristics were used to establish baseline equivalence between students in treatment and control schools. They were also used as covariates in the impact analyses. Student records were available for more than 97% of the students attending study schools.
- **State assessment scores.** Data on prior achievement on state mathematics assessments were collected from the Maine State Department of Education and from each supervisory union in Vermont. Scores were collected for all students on the state mathematics assessment taken the year before the study, when students were in grade 7. The Maine state assessment is given in the spring of each year; the scores collected were from spring 2008. The Vermont state assessment is given in October each year; the scores collected were from fall 2007. Because Maine and Vermont use different tests, it was necessary to translate scores into a common metric. All scores were standardized to Z-scores using the mean and the standard deviation of the test scores within each state, including only schools participating in the study (AR and N-AR samples combined).²⁷

²⁷ Standardizing (using Z-scores) across grades and states is the most powerful and efficient way to combine results from different assessments (May et al., 2009). It is appropriate only if the tests are similar, the tests assess similar constructs across states and grades, and the samples across states and grades are similar and represent similar cross-sections of the population of students targeted by the intervention (May et al., 2009). The first assumption is reasonable, because the Maine and Vermont state standards in middle grades mathematics are similar (Hupp, 2009) and the state achievement tests assess these standards. The second assumption is also reasonable, because the student samples in Maine and Vermont represent similar subpopulations of students demographically (the proportion of girls was 49% in Maine and 50% in Vermont; the proportion of ethnic/racial minority students was 4% in Maine and 4% in Vermont; the proportion of students eligible for free or reduced-price lunch was 41% in Maine and 46% in Vermont; and the proportion of students eligible for special education was 12% in Maine and 15% in Vermont), and in terms of the underlying construct of mathematics achievement, as measured by the Promise Assessment, the pretest measure administered to all study students (Maine: mean = 324.26, standard deviation = 31.20; Vermont; mean = 320.14, standard deviation = 30.46; $\beta = 4.35$, $p = 0.118$). (The difference on pretest was examined using a model that accounts for the clustering of students within schools and included both AR and N-AR students.)

- **Promise Assessment pretest.** The Promise Assessment (Internet Testing Systems and SEG Assessment 2009) is a computer-adaptive mathematics assessment with both a general mathematics (pre-algebra) item bank and an algebra item bank. The general mathematics item bank was used for the pretest. It was administered to all grade 8 students in participating schools in September and October 2008. The pretest presented 30 items that ranged in difficulty from the grade 5 to the grade 8 level. The 30 items were targeted to ability level and drawn from a test bank of approximately 1,000 items. The items were distributed across six domains (number, computation and estimation, measurement, geometry, probability and statistics, and algebraic concepts). The reliability for the 30-item general mathematics Promise Assessment in the calibration group is 0.87. Scores for the Promise Assessment are generated by a linear transformation of the underlying Rasch scale and are reported on a scale of 200 to 400. Response rates on the pretest were 99% for AR students and 97% for N-AR students. (See appendix B for more information on the Promise Assessment.)

Measures of Implementation

- **Online course activity data.** The online course management system that Class.com used to deliver the course (Moodle) automatically logs and stores data documenting online course activity of students, online teachers, and proctors. For all online course sections, Moodle records the date and time that users logged into the system, as well as the sender, recipient, and content of all messages. The software also records the content accessed by students, as well as quiz and exam grades. (Chapter 3 provides details on the information recorded by the course system.) The system also automatically logs records of teachers' and proctors' review of student records. These logs were the primary source of information used to assess online teachers' monitoring of and communication with students. The study team "observed" direct online interactions between online teachers and their students using these archived data. For each of the 10 online course sections, the study team randomly selected one school day each month (October–May) and downloaded all online activity over a 24-hour period. A 24-hour period was observed because it was the amount of time within which online teachers were expected to respond to communications from individual students. Researchers coded the archived data to indicate whether the online teachers logged into the course during each 24-hour period and whether they posted announcements on the home page for their sections; they also recorded the number and type of communications between teachers and students. They collected the 24-hour sample of archived data once a month for 8 months for each of the 10 course sections, for a total of 80 observations. Archived online course data were also the primary source of information on students' progression through the course (that is, course completion).
- **Site visits.** Study team members visited every treatment school once during the 2008/09 school year, in order to assess the extent to which the online course was being implemented as intended. At each school, researchers noted the physical location of students taking the online course and proctor activities while students accessed the course. (A copy of the protocol used for these visits is provided in appendix B.)
- **Proctor logs.** Proctors who supervised the students in the online course were asked to complete a web-based log once a week to record the amount of time they spent

performing specific types of activities as part of their proctor role. Data from the logs were used to monitor implementation across treatment schools. All proctors completed at least half of their weekly logs. (A description of the proctor logs is provided in appendix B.)

- **Teacher survey.** Researchers administered a web-based teacher survey in spring 2009 to all grade 8 mathematics teachers in study schools and to online Algebra I teachers. The survey served two main purposes. First, it provided data on characteristics of the teachers (for example, degree earned, years of teaching experience). Second, it provided data on the delivery of grade 8 mathematics instruction in treatment and control schools, as well as in the online Algebra I classes. The response rate on the teacher survey was 95%. (A description of the teacher survey and the key constructs used in this report is provided in appendix B.)
- **Classroom materials.** To describe the characteristics of the regular grade 8 mathematics classes in study schools, the study team used a structured protocol to collect instructional materials, including teacher-provided information on the textbook used and actual course syllabi, exams, and pacing guides (if available). The study team coded these materials for content by using the list of mathematics concepts included on the teacher survey. It then calculated the proportion of concepts covered to estimate the amount and type of algebraic concepts taught in the general grade 8 mathematics classes. Classroom instructional materials were obtained for 90% of grade 8 mathematics classes in study schools. (Appendix B describes the collection and coding of classroom materials.)

Outcome Measures

Promise Assessment posttests. The Promise Assessment posttest was administered to all grade 8 students in participating schools in May and June 2009. The posttest was delivered as a 40-item that included 20 items from the general mathematics item bank and 20 items from the algebra item bank.

The algebra item bank contains approximately 300 items. The reliability of the 20-item test drawn from this bank in the calibration group is 0.80. Scores on the algebra posttest are reported on a scale of 400 to 500. These scores represent the primary achievement measure at the end of grade 8. Scores on the general mathematics posttest, reported on a scale of 200 to 400, represent a secondary measure of achievement at the end of grade 8. The reliability for the 20-item general mathematics assessment in the calibration group is 0.83. Response rates on the algebra and general mathematics posttests were 99% for AR students and 94% for N-AR students. However, scores based on less than five minutes of testing were determined to be invalid by the test developer and thus were dropped and treated as missing. For the algebra posttest, there were fewer than four such cases in the AR sample and 118 in the N-AR sample (73 in treatment and 45 in control). Eight percent of the algebra posttest scores were cut from the N-AR sample because of testing time of less than five minutes.

High school mathematics coursetaking. To measure coursetaking after grade 8, the study team drew on two sources of data. For both AR and N-AR students, it gathered data on students' planned grade 9 mathematics classes. For AR students only, it gathered actual course enrollment and grades for grade 9 and planned coursetaking for grade 10.

- **Planned grade 9 mathematics classes (collected at the end of grade 8) for all students.** In spring 2009, study team members collected planned grade 9 course enrollment information for all grade 8 students in study schools. These data were provided by participating schools, which in many cases contacted the high schools students planned to attend to obtain the information. The study team collected the name of the high school and the course title for the grade 9 mathematics course in which each student was enrolled for fall 2009. These data were made available to the study team for 97% of AR and 93% of N-AR students.
- **Grade 9 and 10 mathematics course sequences (collected at the end of grade 9) for AR students.** In spring 2010, for all AR students in the sample, the study team collected course titles and grades for the mathematics courses taken in grade 9 and course titles for the mathematics courses in which students planned to enroll for grade 10. These data were collected from the high schools AR students attended in grade 9. Codeable data for 427 AR students (97% of the sample) were obtained. These data were not collected for the N-AR students because of cost constraints and the determination that assessing the impact of online Algebra I in grade 8 on subsequent coursetaking was most critical and relevant for the AR students.

Coding of high school coursetaking data was based on methods used by the National Center for Education Statistics for the National Assessment of Educational Progress and Education Longitudinal Study transcript studies. Transcript coding protocols guided the extraction of course identifiers. Mathematics education experts coded the course titles, using the Classification of Secondary School Courses, which is based on information available in school catalogs and other information sources (U.S. Department of Education 2007b).

The creation of the coursetaking indicators based on these codes was guided by previous research on typical high school course sequencing and definitions of “advanced,” “intermediate,” or “low” high school course sequences by Schneider and colleagues (1998) and Stevenson and colleagues (1994). In U.S. high schools, the typical sequence is Algebra I → Geometry → Algebra II → Pre-calculus/Trigonometry → Calculus. Advanced, intermediate, and low sequences are defined by where students are in this pipeline during each year of high school. The study team drew on this research to define two coursetaking sequences for the study: “advanced” for AR students and “intermediate” for N-AR students.

For AR students (who were followed into high school), the study team coded whether their actual grade 9 courses and grades and planned grade 10 courses were indicative of an advanced sequence, defined by Schneider and colleagues (1998) as the successful completion of Geometry and Algebra II by grade 10.

AR students who met the following criteria were coded as participating in an advanced course sequence:

- Completed a full-year course above Algebra I or equivalent in grade 9.
- Earned an end-of-year grade of C or above in the grade 9 course (if more than one grade 9 course was taken, the grade had to be C or higher in the most advanced course taken to meet this criterion).
- Enrolled in Algebra II (or the next course in the sequence) for grade 10.

Students who did not meet all three criteria were coded as not participating in an advanced course sequence.²⁸

The collection and coding of coursetaking for N–AR students was different from that for AR students in two respects. First, the study team collected data about planned courses for N–AR students at the end of grade 8 but did not follow these students into high school. Second, because these students were not identified as ready for algebra as rising grade 8 students, researchers assumed that they would not follow an advanced sequence in high school. They therefore coded whether their planned grade 9 courses were indicative of an intermediate sequence, defined by Schneider and colleagues (1998) as the successful completion of Algebra I in grade 9 and Geometry in grade 10. N–AR students were assigned codes for planned grade 9 courses according to whether or not the course for grade 9 was at or above Algebra I. (Appendix B provides more information on the collection and coding of high school courses.)

Characteristics of the Study Sample

This section examines baseline equivalence at three time points: (1) at the time of random assignment; (2) at the time of analysis, with no imputation of missing cases; and (3) at the time of analysis, where missing data are imputed.

School Characteristics at Random Assignment

Table 2-6 summarizes the characteristics of the sample of study schools in the year before the study. Baseline measures, pertaining to the 2007/08 school year, indicate the following:

- The average total enrollment for study schools was 186 students. Average grade 8 enrollment was 32.
- 94% of the schools were Title I schools.
- 48% of the students were eligible for free or reduced-price lunch.
- 95% of the students were white.
- 53% of the students scored at or above the proficiency level on the state mathematics assessment in the 2007/08 school year.

²⁸ For AR students, the study team also collected and coded the planned grade 9 courses (based on end-of-grade 8 enrollments) as a binary variable representing initial registration in a course above Algebra I versus at or below Algebra I. Chapter 5 reports the impact of online Algebra I on AR students' initial course registrations.

Table 2-6. Baseline Middle School Characteristics in 2007/08 before Random Assignment

Characteristic	All schools (<i>n</i> = 68)		Treatment schools (<i>n</i> = 35)		Control schools (<i>n</i> = 33)		<i>p</i> -value
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	
Eligible for free or reduced-price lunch (average percent) ^a	48	15.73	50	14.49	47	16.94	0.337
Race/ethnicity (average percent)							
White	95	11.08	95	5.93	94	14.82	0.716
Black	1	2.55	2	3.42	1	0.80	0.122
Hispanic	1	2.06	1	2.41	1	1.66	0.42
Asian/Pacific Islander	1	1.48	1	1.90	1	0.83	0.353
Other	2	10.32	1	1.87	3	14.69	0.332
Female (average percent)	48	5.08	47	4.56	48	5.63	0.705
Proficient on state mathematics assessment (average percent)	53	13.71	53	11.32	53	16.04	0.947
Student-teacher ratio	8.37	2.46	8.50	2.43	8.24	2.52	0.786
Number of grade 8 students	32	37.00	31	40.93	33	32.96	0.889
Total school enrollment	186	133.86	180	130.89	192	138.67	0.773
	Percent	Standard deviation	Percent	Standard deviation	Percent	Standard deviation	<i>p</i> -value
Title I status (percent of schools)	94	na	†	na	†	na	0.288

na is not applicable.

a. Data were missing for fewer than four schools

Note: Sample includes 68 schools (35 treatment, 33 control). Values are unadjusted. Logistic regression models with treatment status as the dependent variable were used to determine whether the means for the study groups were significantly different from one another.

† To maintain confidentiality of participants, the percentage was suppressed for presentation purposes.

Source: School-level data obtained from the Common Core of Data for school year 2007/08.

Table 2-7 summarizes the characteristics of students in the participating schools as of fall 2008. It shows baseline characteristics for the AR and N-AR samples overall (across conditions) and by condition.

Table 2-7. Baseline Student Characteristics of AR and N-AR Student Samples at Random Assignment (Missing Data Not Imputed)

Characteristic	Overall	Treatment	Control	p-value
<i>AR students</i>				
Percent eligible for free or reduced-price lunch (<i>n</i> = 436)	32	34	30	0.596
Percent receiving special education services (<i>n</i> = 437)	3	3	4	0.622 ^a
Percent limited English proficient (<i>n</i> = 437)	3	5	2	0.646 ^a
Percent female (<i>n</i> = 440)	49	49	49	0.833
Percent racial/ethnic minority (<i>n</i> = 440)	7	8	5	0.975
Mean grade 7 score on state mathematics assessment (standardized) ^b (<i>n</i> = 437)	0.95 (0.69)	0.97 (0.59)	0.94 (0.77)	0.584
Mean fall 2008 Promise Assessment pretest score ^c (<i>n</i> = 435)	349.87 (23.27)	353.61 (22.33)	346.14 (23.64)	0.035
<i>N-AR students</i>				
Percent eligible for free or reduced-price lunch (<i>n</i> = 1,403)	46	46	47	0.883
Percent receiving special education services (<i>n</i> = 1,419)	17	19	16	0.255
Percent limited English proficient (<i>n</i> = 1,419)	3	4	2	0.927 ^a
Percent female (<i>n</i> = 1,439)	50	49	50	0.731
Percent racial/ethnic minority (<i>n</i> = 1,438)	5	7	4	0.596 ^a
Mean grade 7 score on state mathematics assessment (standardized) ^b (<i>n</i> = 1,403)	-0.24 (0.86)	-0.25 (0.84)	-0.22 (0.89)	0.609
Mean fall 2008 Promise Assessment pretest score ^c (<i>n</i> = 1,384)	312.60 (27.23)	313.72 (27.01)	311.41 (27.43)	0.248

Note: AR is algebra ready. N-AR is not algebra ready.

Sample includes 68 schools (35 treatment, 33 control); Full samples included 440 AR students (218 treatment, 222 control); and 1,445 N-AR students (744 treatment, 701 control); 4 control schools had no N-AR students. Student sample sizes vary for each row, based on the amount of missing data for each student characteristic.

Values are unadjusted. Differences in student characteristics by condition were tested using a model that accounts for the clustered data structure and blocking used for randomization. Figures in parentheses are standard deviations.

a. The model did not converge to produce estimates when controlling for five state by size dummy blocking variables. Reported *p*-value represents a model that controls for state and two dummy indicators for medium and large schools rather than their interactions.

b. State mathematics scores were standardized by using the mean and standard deviation of the test scores within each state, including only schools participating in the study. Data were missing for 3 AR students (1 from treatment schools, and 2 from control schools); data were also missing for 42 N-AR students (23 from treatment schools, and 19 from control schools)

c. The Promise Assessment test was administered in the first month of the school year and is therefore not a pure pretreatment measure. Data were missing for 5 AR students (1 from treatment schools, and 4 from control schools); data were also missing for 61 N-AR students (30 from treatment schools, and 31 from control schools).

Source: Maine state department of education and Vermont supervisory unions; study records.

AR versus N-AR Student Sample Characteristics at Random Assignment

In table 2-7, the characteristics of AR and N-AR students are not directly compared. Appendix A, table A-1 provides details on the AR and N-AR samples including the significance tests of differences in their characteristics. As previously noted, decisions about which students were AR were made by each school, not on the basis of an objective criterion applied across schools. This school-determined process appeared to result in AR and N-AR samples that were statistically significantly different on several dimensions:

- 32% of AR and 46% of N-AR students in the study were eligible for free or reduced-price lunch.
- 3% of AR and 17% of N-AR students received special education services.
- On average, AR students scored nearly 1 standard deviation above the sample mean on their grade 7 state mathematics test ($z = 0.95$). The average among N-AR students was 0.24 standard deviations below the mean.
- In fall 2008, the average pretest score for AR students was 349.9 (standard deviation = 23.3); for N-AR students, the average pretest score was 312.6 (standard deviation = 27.2).

Thus AR students scored significantly higher on measures of prior mathematics achievement than N-AR students. They were also less likely to be eligible for free or reduced-price lunch or to receive special education services than N-AR students. AR and N-AR students were similar on other demographic characteristics, including gender, race/ethnicity, and English proficiency.

Baseline Equivalence of AR and N-AR Treatment and Control Groups at Random Assignment

The purpose of random assignment is to produce groups that are comparable on measured and unmeasured characteristics, to rule out any explanations other than chance or a treatment effect for postintervention differences between the groups. Differences between the treatment and control groups did not differ significantly from zero across measured demographic characteristics and prior mathematics achievement based on pre-random assignment data from the prior school year (table 2-6 and 2-7).

In contrast, students in treatment and control schools in the AR sample differed significantly on the study-administered pretest administered after random assignment, in September-October 2008. Specifically, AR students in treatment schools outperformed their counterparts in the control group. Additional sources of baseline information indicated that observed differences between AR students in treatment and control schools may be related to schools' assignment to the treatment condition rather than chance. There was no observed difference by condition on the state mathematics assessment scores from the year before the study or on any other measured demographic characteristics that are correlated with achievement.

In addition to an observed difference in AR students' scores by condition on the study-administered pretest, there was an observed difference by condition in the amount of time spent by AR students on the pretest. The computer-adaptive pretest records the amount of time (minutes and seconds) each test-taker spent on the test. Analysis of testing times by condition revealed that AR students in treatment schools spent an average of approximately five minutes longer on the pretest than AR students in control schools ($p = 0.028$; see appendix B, tables B-3 and B-4 for results of the testing time analyses). These results suggest that the study-administered pretest was administered to or regarded differently by AR students in treatment and control schools, introducing a potential bias in favor of the treatment students that does not reflect an actual difference in knowledge at the start of the study. To avoid this potential bias, researchers used the prior year's state mathematics assessment, which was administered before the launching of the study, random assignment, or implementation of the intervention, rather than the study-administered pretest as an unbiased measure of baseline mathematics achievement.

Baseline Equivalence of AR and N-AR Treatment and Control Groups at Analysis

Researchers also examined the baseline equivalence of the treatment and control groups for the AR and N-AR samples used in the analysis. Analyses testing baseline equivalence are provided with two sets of study samples. First, table 2-8 shows student characteristics for the AR and N-AR student samples that include all students with complete data on the primary outcomes (algebra posttest scores and high school coursetaking codes). Second, table 2-9 shows student characteristics for all students included in the main analyses, where missing data were imputed.²⁹

Table 2-8. Baseline Characteristics of Algebra-Ready and Non-Algebra Ready Samples at Analysis for Students with Complete Outcome Data

Characteristic	Sample with Non-Missing Algebra Scores				Sample with Non-Missing Coursetaking Codes			
	Overall	Treatment	Control	<i>p</i> -value	Overall	Treatment	Control	<i>p</i> -value
<i>AR students</i>								
Percent eligible for free or reduced-price lunch	32	34	29	0.484	32	34	29	0.533
Percent receives special education services	3	3	4	0.681	3	2	4	0.547
Percent limited English proficient	3	5	2	0.796	3	4	2	0.706
Percent female	49	49	49	0.836	49	49	49	0.782
Percent racial/ethnic minority	7	8	6	0.825	7	8	6	0.774
Mean grade 7 score on state mathematics assessment (standardized) ^a	0.95 (0.68)	0.97 (0.59)	0.93 (0.76)	0.584	0.96 (0.69)	0.98 (0.59)	0.94 (0.77)	0.499
Mean fall 2008 Promise Assessment pretest score ^b	349.74 (23.30)	353.45 (22.36)	346.04 (23.69)	0.039	349.82 (23.53)	353.52 (22.58)	346.16 (23.93)	0.047
Total number of AR students ^c	434	216	218		427	211	216	
<i>N-AR students</i>								
Percent eligible for free or reduced-price lunch	45	45	45	0.715	46	46	46	0.675
Percent receives special education services	16	18	14	0.086	17	18	15	0.242
Percent limited English proficient	3	4	1	0.741	3	4	1	0.247
Percent female	51	50	52	0.478	50	50	50	0.765
Percent racial/ethnic minority	5	6	3	0.577	5	7	3	0.659
Mean grade 7 score on state mathematics assessment (standardized) ^a	-0.19 (0.84)	-0.21 (0.83)	-0.18 (0.85)	0.627	-0.23 (0.83)	-0.24 (0.83)	-0.22 (0.83)	0.586
Mean fall 2008 Promise Assessment pretest score ^b	313.81 (26.83)	315.01 (26.57)	312.57 (27.07)	0.330	313.08 (27.05)	314.30 (26.65)	311.79 (27.43)	0.407
Total number of N-AR students ^d	1,241	630	611		1,349	697	652	

AR is algebra ready. N-AR is not algebra ready.

Values are unadjusted. Differences in student characteristics by condition were tested using a model that accounts for the clustered data structure and blocking used for randomization. Figures in parentheses are standard deviations.

a. State mathematics scores were standardized by using the mean and standard deviation of the test scores within each state, including only schools participating in the study.

²⁹ The rate of missing data on outcome measures was 1%–3% for the AR sample and 7%–14% for the N-AR sample. See appendix F for details about missing data and multiple imputation, and for a comparison of the characteristics of students with and without missing outcome data, see tables F-2 – F-5.

b. The Promise Assessment test was administered in the first month of the school year and is therefore not a pure pretreatment measure.

c. 434 AR students have algebra posttest data, and 427 AR students have coursetaking codes (indicators of advanced vs. not-advanced high school coursetaking as of spring of grade 9). Of the students with algebra posttest scores, 4 are missing free and reduced price lunch status, 3 are missing special education status, 3 are missing LEP status, 3 are missing state mathematics scores, 4 are missing study-administered pretest data, and 0 are missing gender or race/ethnicity data. Of the students with coursetaking codes, 3 are missing free and reduced price lunch status, 3 are missing special education status, 3 are missing LEP status, 3 are missing state mathematics scores, 3 are missing study-administered pretest data, and 0 are missing gender or race/ethnicity data.

d. 1,241 N-AR students have complete algebra posttest data, and 1,349 N-AR students have coursetaking codes (indicators of intermediate vs. not-intermediate coursetaking as of spring of grade 8). Of the students with algebra scores, 31 are missing free and reduced price lunch status, 18 are missing special education status, 18 are missing LEP status, 29 are missing state mathematics scores, 38 are missing study-administered pretest data, 2 are missing gender data, and 2 are missing race/ethnicity data. Of the students with coursetaking codes, 37 are missing free and reduced price lunch status, 23 are missing special education status, 23 are missing LEP status, 37 are missing state mathematics scores, 47 are missing study-administered pretest data, 5 are missing gender data, and 6 are missing race/ethnicity data.

Source: Maine state department of education and Vermont supervisory unions.

Table 2-9. Baseline Characteristics of AR and N-AR Samples at Analysis (Missing Data Imputed)

Characteristic	Overall	Treatment	Control	<i>p</i> -value
<i>AR students</i>				
Percent eligible for free or reduced-price lunch	32	34	30	0.605
Percent receiving special education services	4	3	4	0.572 ^a
Percent limited English proficient	3	5	2	0.646 ^a
Percent female	49	49	49	0.833
Percent racial/ethnic minority	7	8	5	0.975
Mean grade 7 score on state mathematics assessment (standard deviation) ^b	0.90 (0.72)	0.93 (0.63)	0.88 (0.81)	0.608
Mean fall 2008 Promise Assessment pretest score (standard deviation) ^c	349.81 (23.36)	353.55 (22.33)	346.04 (23.76)	0.038
Total number of AR students	440	218	222	
<i>N-AR students</i>				
Percent eligible for free or reduced-price lunch	48	48	48	0.863
Percent receiving special education services	18	19	17	0.236
Percent limited English proficient	3	5	2	0.989 ^a
Percent female	50	49	50	0.718
Percent racial/ethnic minority	5	7	4	0.592 ^a
Mean grade 7 score on state mathematics assessment (standard deviation) ^b	-0.28 (0.91)	-0.28 (0.91)	-0.27 (0.91)	0.872
Mean fall 2008 Promise Assessment pretest score (standard deviation) ^c	311.81 (27.67)	313.01 (27.31)	310.54 (28.00)	0.238
Total number of N-AR students	1,445	744	701	

AR is algebra ready. N-AR is not algebra ready.

Note: Sample includes 68 schools (35 treatment, 33 control); 440 AR students (218 treatment, 222 control); and 1,445 N-AR students (744 treatment, 701 control); 4 control schools had no N-AR students. Values represent unadjusted means. Estimates were averaged across 10 multiply imputed datasets. Differences in characteristics by condition were tested using a model that accounts for the clustered data structure and blocking used for randomization. Figures in parentheses are standard deviations.

a. Model does not estimate when controlling for five state by size dummy blocking variables. Reported *p*-value represents a model that controls for state and two dummy indicators for medium and large schools rather than their interactions.

b. State assessment scores were standardized by using the mean and standard deviation of the test scores within each state, including only schools participating in the study.

c. Promise Assessment test was administered in the first month of the school year and is therefore not a pure pretreatment measure.

Source: Maine state department of education and Vermont supervisory unions.

Tables 2-8 and 2-9 show that, as was the case at random assignment, differences between treatment and control groups were not statistically significant across measured demographic characteristics or prior mathematics achievement, except on the study administered pretest at the time of analysis. At analysis, AR students in treatment schools scored significantly higher than their counterparts in control schools (means = 353.45 and 346.04, respectively, for the AR treatment and control groups with complete algebra posttest data, $p = 0.039$; means = 353.52 and 346.16, respectively, for the AR treatment and control groups with complete coursetaking data, $p = 0.047$; and means = 353.55 and 346.04, respectively, for the AR treatment and control groups with missing cases imputed.)

Characteristics of Teachers in Study Schools

There were no significant differences in the average number of mathematics teachers per school by condition ($p = 0.997$) (table 2-10). These numbers do not include the online teachers, who were additional to the treatment schools' teaching staff (there was one online teacher per school). (Multiple schools shared a single online teacher.) Chapter 3 provides more information on the allocation of online teachers to treatment schools.

Table 2-10. Number of Grade 8 Mathematics Teachers (Excluding Online Teachers)

State	Treatment schools ($n = 35$)			Control schools ($n = 33$)			p -value
	Total number of teachers	Mean per school	Standard deviation	Total number of teachers	Mean per school	Standard deviation	
Maine	36	1.44	0.65	39	1.56	0.82	0.569
Vermont	16	1.60	1.35	10	1.25	0.46	0.495
Total	52	1.49	0.89	49	1.48	0.76	0.997

Note: Tests of significance were conducted using two-tailed, independent sample t-tests.

Source: Study records.

Two-thirds of the schools had a single grade 8 mathematics teacher, and 24 percent had two grade 8 mathematics teachers; in 90% of schools, a primary mathematics teacher provided instruction to grade 8 students and a second teacher provided instruction to particular groups of students (special education, gifted and talented). The remaining 10% of schools had three, four, or five grade 8 mathematics teachers (table 2-11).

Table 2-11. Percentage of Participating Schools with Various Numbers of Grade 8 Mathematics Teachers (Excluding Online Teachers)

Number of grade 8 mathematics teachers in school	Overall		Treatment		Control		<i>p</i> -value
	Number	Percent	Number	Percent	Number	Percent	
1	45	66	24	69	21	64	0.867
2	16	24	7	20	9	27	0.201
3 or more	7	10	4	11	3	9	0.940
Total	68	100	35	100	33	100	—

— is not appropriate to calculate because schools were randomly assigned to treatment or control.

Note: Sample includes 68 schools (35 treatment, 33 control). Tests of significance were conducted using two-tailed χ^2 tests. Schools with three, four, and five mathematics teachers were collapsed into one group to protect the confidentiality of schools. Totals may not sum to 100 percent because of rounding.

Source: Study team calculations based on school rosters and teacher survey records.

Table 2-12 summarizes the background characteristics of the teachers in study schools, including online teachers and grade 8 mathematics teachers in both treatment and control schools. The background characteristics are based on information collected from the teacher survey conducted in spring 2009. These data indicate that the regular grade 8 mathematics teachers at treatment and control schools were similar in terms of education, gender, race/ethnicity, number of years teaching, and certification to teach secondary mathematics.³⁰ More online teachers than teachers in the treatment or control schools were certified to teach secondary mathematics and had master's degrees or higher degrees (approximately 75% of online teachers vs. approximately 38% of regular teachers in treatment schools and approximately 20% of regular teachers in control schools). Online teachers also had significantly more experience teaching algebra than classroom teachers (9.5 years for online teachers versus 2.3 years for regular teachers in treatment schools and 3.7 years for regular teachers in control schools). There were no differences in the total number of years teaching or the number of years spent teaching middle school mathematics.

³⁰ Certification data are based on teachers' self-reports of certification status.

Table 2-12. Background Characteristics of Online and Regular Grade 8 Mathematics Teachers

Characteristic	Online teachers (all in treatment schools)		Regular teachers in treatment schools		Regular teachers in control schools		Online teachers vs. Regular teachers in treatment schools		Online teachers vs. Regular teachers in control schools		Regular teachers in treatment schools vs. Regular teachers in control schools	
	Number	Percent	Number	Percent	Number	Percent	Percent Difference	p-value	Percent Difference	p-value	Percent Difference	p-value
Certified in secondary mathematics	8	100	22	39	20	37	61	0.003	63	0.003	2	0.959
Master's degree or above	‡	†	21	38	11	20	†	0.017	†	0.001	18	0.060
Female	‡	†	27	48	26	48	†	0.236	†	0.087	0	0.988
White	‡	†	44	79	43	80	†	0.789	†	0.851	1	1.000
	Mean		Mean		Mean		Mean Difference		Mean Difference		Mean Difference	
	Standard deviation		Standard deviation		Standard deviation		p-value		p-value		p-value	
Years of teaching experience (total)	22.87	13.15	14.8	9.17	14.69	9.77	8.07	0.034	8.18	0.043	0.11	0.955
Years teaching middle school mathematics	6	8.47	9.78	7.93	10.64	8.8	-3.78	0.220	-4.64	0.173	-0.86	0.616
Years teaching Algebra I	9.5	6.48	2.29	3.67	3.71	5.25	7.21	0.001	3.13	0.008	-1.42	0.135

Note: Sample includes 68 schools and 117 teachers (8 online teachers, 56 regular teachers in treatment schools, and 53 regular teachers in control schools). Survey data were missing for 14 teachers. The difference between two groups is indicated by $(y - x)$. Tests of significance for categorical variables were conducted using two-tailed, χ^2 tests. Tests of significance for continuous variables were conducted using two-tailed, ANOVA models. To maintain the confidentiality of participants, measures with fewer than three missing data cases were suppressed for presentation purposes.

‡ To maintain confidentiality of participants, the number was suppressed for presentation purposes.

† To maintain confidentiality of participants, the percentage was suppressed for presentation purposes.

Source: Teacher survey.

Characteristics of High Schools Attended by AR Students

To collect follow-up information on the mathematics courses-taking in high school by AR students, at the end of grade 8 researchers gathered information about which high school each AR student was planning to attend the following year. When the students were in grade 9, researchers contacted the high schools to confirm the enrollment of each student. Sixty-six high schools received AR students (45 public schools and 21 private schools). The high schools attended were in Maine (43 schools), Vermont (16 schools), and other states (7 schools). The number of AR students enrolled in each high school varied from fewer than 4 to 29. The characteristics of the high schools attended by AR students are shown in table 2-13.

Of the 66 high schools, 41% received AR students from treatment schools only, 36% received AR students from control schools only, and 23% received AR students from a both treatment and control schools. Within the high schools that received students from both conditions, 45% of the AR students were from treatment schools and 55% were from control schools.

Table 2-13. Characteristics of High Schools That Received AR Students in 2008/09

Characteristic	Number	Mean	Standard deviation
Eligible for free or reduced-price lunch (average percent) ^a	43	34	13.66
Race/ethnicity (average percent)			
White	63	89	14.91
Black	63	2	3.73
Hispanic	63	2	1.43
Asian/Pacific Islander	63	4	6.16
Native American	63	3	12.01
Female (average percent)	63	49	8.63
Proficient on state mathematics assessment (average percent)	47	35	13.67
Student-teacher ratio	63	10	2.63
Number of grade 9 students	62	114	79.75
Total school enrollment	63	502	311.42

Note: Sample includes 66 high schools; 45 (68%) were public schools and 21 (32%) were private schools. No data were available for three private high schools.

Free or reduced-price lunch data were unavailable for any of the 21 private high schools because they do not participate in the National School Lunch Program.

Source: Data on public high schools are from the Common Core of Data (2007/08). Data on private schools are from the Private School Universe Survey (2007/08).

Estimation Methods

All analyses were conducted separately on the AR and N-AR student samples. The samples used for analyses are intent-to-treat samples, meaning that all students with consent who were identified as AR before random assignment were included in the AR student sample, whether or not they enrolled in or stuck with the online Algebra I course.

Consistent with the research questions that frame the study, the two primary analyses assess the impact of online Algebra I on the algebra test scores of AR students and their likelihood of participating in an advanced course sequence in high school.

Four secondary analyses assess the impact of online Algebra I on:

- AR students' general mathematics scores
- N-AR students' algebra scores
- N-AR students' general mathematics scores
- N-AR students' likelihood of participating in an intermediate course sequence in high school (based on planned grade 9 courses).

Given the nested structure of the data (the clustering of students within schools), multilevel models were used to estimate the impacts of online Algebra I on the primary and secondary study outcomes. For each student-level outcome, two-level hierarchical models were used, with students nested within schools.

To increase the precision of the estimates in these analyses, researchers used a set of baseline characteristics of schools and students as covariates. The following covariates were included in the outcome analyses:

- School level (blocking variables)
 - State
 - School size (based on the number of grade 8 students enrolled in spring 2008)
- Student level
 - Baseline mathematics achievement scores on the state mathematics assessment from the year before the study
 - Student-level demographic information (gender, eligibility for free or reduced-price lunch, special education status).

In addition to estimating the main impact models, researchers also conducted sensitivity analyses. Six sensitivity analyses were conducted to test the robustness of the observed estimates from the benchmark impact model on AR students' algebra scores; another six sensitivity analyses tested the robustness of the high school coursetaking outcome. These analyses tested models with different methods of accounting for students' baseline mathematics achievement, a model with no covariates, a model based on observed (nonimputed) data only, and a model that tested an alternative nesting structure (with students in treatment schools clustered within online teachers).

Researchers also conducted 10 sensitivity analyses to test the robustness of the findings for N-AR students' outcomes. For each outcome, these analyses test three models with different methods of accounting for students' baseline mathematics achievement, a model with no covariates and a model based on observed (nonimputed) data only.

Treatment of Missing Data

Rates of missing data on baseline covariates and outcome measures were 1% – 3% for the AR sample and less than 1% – 14% for the N-AR sample (see table F-1 in appendix F). The highest rates of missing data for the N-AR student sample were on the algebra posttest. On this measure,

14% of the sample was missing because of absence or attrition (6%) or because the score was eliminated because the student spent less than five minutes on the test (8%) (see table F-1 in appendix F).

To handle missing data, researchers used multiple imputation by chained equations. Multiple imputation models were specified on the basis of the analysis of predictors of missingness; they included student and school covariates and interaction terms between student covariates.³¹ Within both the AR and N-AR samples, multiple imputation was conducted for the treatment and control groups separately. Appendix E provides the results of sensitivity analyses testing whether results were affected by the imputation. Appendix F provides more information on missing data patterns and the multiple imputation procedure.

Statistical Precision and Significance Testing

Two-tailed *t*-tests were used to assess the statistical significance of the average impact estimates. If an impact estimate was statistically significant, it is possible to conclude with some confidence that the online Algebra I course had an effect on the outcome being assessed. If an impact estimate was not statistically significant, the nonzero estimate may be a product of chance. Statistical significance does not capture the magnitude or meaning of an impact estimate, only the probability that an effect of the size observed might occur if the true impact were zero. Statistically significant impacts may or may not be policy relevant.

Multiple Hypothesis Testing

This study takes different approaches to multiple hypothesis testing for the primary and secondary analyses, because the framework for determining whether the intervention was “successful” was based on criteria that establish different types of hypotheses. The criteria, stated in chapter 1, are repeated here:

- A statistically significant positive impact on either of the two primary research questions (AR students’ algebra scores at the end of grade 8 or high school coursetaking).
- The absence of statistically significant negative side effects (as assessed by the four secondary research questions).³²

For the primary analyses, intervention success is achieved if a positive impact on either of the two primary outcomes is detected (criterion 1). For this analysis, an adjustment was applied to account for multiple comparisons. Specifically, to maintain the probability of falsely detecting a statistically significant result ($p < .05$) if there were no true impact on either of the two primary

³¹ In addition to this model, the study team explored a second imputation model that included school-level fixed effects (dummy variables for each school). However, because of the large number of school dummy variables needed (68) and the presence of low-incidence binary variables (such as racial/ethnic minority status in this sample), the fixed-effect approach was an inappropriate method for use with the sample (see appendix F).

³² For the secondary research questions, the study was not designed to determine whether the groups were statistically equivalent. A lack of statistical significance for an impact estimate does not mean that the impact being estimated equals zero. Rather, it means that the estimate cannot reliably be distinguished from zero, an outcome that may reflect the small magnitude of the impact estimate, the limited statistical power of the study, or both.

outcomes, the study team adjusted the statistical significance level for each of the two primary outcomes to 2.5% (Bonferroni correction). For primary analyses in this report, statistical significance is denoted in the tables by an asterisk when the p -value of the impact estimate is less than or equal to 0.025.

For the four secondary analyses, adjustments for multiple comparisons were not applied. Making such adjustments would have made the tests less conservative, because on these questions, a desirable outcome in favor of the intervention is a lack of statistically significant side effects. Had the statistical significance level for these tests been reduced, it would have been easier to conclude that there were no detectable side effects than if the level at 5% for each test had been maintained. The study team thus opted for the more conservative approach of maintaining 5% significance for each test. Multiple comparisons adjustments were not applied for the two exploratory impact analyses, which are reported in chapter 5. For secondary analyses, statistical significance is denoted in the tables by an asterisk when the p -value of the impact estimate is less than or equal to 0.05.

Chapter 3 Implementation of the Intervention

The purpose of this chapter is twofold: it describes the online Algebra I course intervention and how it was implemented in the study and describes the regular grade 8 mathematics instruction provided in treatment and control schools. The chapter begins with an overview of the responsibilities of the participating schools and the online course provider and a description of the formation of the online Algebra I classes.

The rest of the chapter describes mathematics instruction for AR and N-AR students in treatment schools and control schools in terms of the six programmatic features of the intervention defined in Chapter 1. The first section details the implementation of the online course in treatment schools with a focus on the *mode of instruction* and *course content*. The second section describes the mode of instruction and content of the mathematics courses provided to N-AR students in treatment schools (that is, students who did not take the online course), and of the mathematics courses provided to AR and N-AR students in control schools (who did not have access to an online Algebra I course). The third section describes and compares the mathematics instruction delivered to AR and N-AR students in treatment and control schools in terms of *teacher qualifications*, *staffing intensity*, *class size*, and *ability grouping*.

Overview of the Intervention: Course Provider and School Responsibilities

Class.com Responsibilities

A variety of online learning models are available. One option is for a school to purchase a “seat” in an online course from an online course provider for each student it wants to enroll.³³ In this model, the online course provider is responsible for overseeing the operation of the online course, including hiring, training, and supervising the online teacher. Based on the constraints that rural schools may encounter that prevent them from offering a face-to-face online Algebra I course—such as the lack of a teacher qualified to teach Algebra I or the small number of AR students—REL-NEI determined that this was an appropriate model to test for the study.

As described in chapter 1, the study team selected Class.com to deliver the yearlong online Algebra I course that was the intervention for the study. Class.com provided a senior mathematics specialist whose role involved hiring and supervising the online teachers and ensuring that the course curriculum was taught as intended.

In June 2008, Class.com hired eight teachers from its network of mathematics teachers to serve as online teachers for the study. All teachers were certified to teach mathematics and met both states’ “highly qualified teacher” content knowledge criteria.³⁴

All online teachers attended a two-day training workshop at Class.com headquarters about a month before the beginning of the school year; six teachers also attended an optional one-day

³³ As of the 2010/11 academic year, the cost of purchasing a seat in one of Class.com’s Algebra I courses was \$700 a year.

³⁴ According to the No Child Left Behind Act (NCLB), a “highly qualified” secondary teacher must demonstrate subject matter competence in each subject he or she teaches (see Title IX, Part A, Section 9101 (23) for a complete definition of “highly qualified”). The online teachers met Maine and Vermont’s content knowledge criteria for being highly qualified; they were not required to be certified in either state.

workshop in January. The purpose of the summer training was to familiarize the teachers with the structure and operation of the online course, demonstrate how to operate the courseware and use the embedded communication tools, and suggest methods for guiding student progress. The January workshop reviewed the topics presented in the summer workshop.

Class.com also provided a senior mathematics specialist to oversee the administration of the online course. This specialist was a Class.com employee who had helped develop the Algebra I course and who had a background in mathematics education. Class.com hosted the online course on its servers, assigned students (by school) and teachers to online course sections, and was responsible for ensuring that the online course was in place and running continuously in all treatment schools throughout the school year, regardless of the schools' start and end dates for the academic year. According to archival data from the Class.com management system, as well as study team communication with participating schools, Class.com fulfilled these requirements, and the course was delivered without interruption during the 2008/09 school year. No reports or observations were made of any Class.com–related technical problems interfering with students' access to the course during the school year.

School Responsibilities

During recruitment, the study team informed all schools that if assigned to the treatment group, their implementation of the online course would have to meet four requirements.

1. Schools were required to provide each AR student with in-school access to a computer with a high-speed Internet connection and the appropriate web browser application.
2. Schools were to assign AR students to a regular class period during which they would access the online course. This period needed to meet with the same frequency and duration as the school's regular grade 8 mathematics classes.
3. Schools were required to provide a school staff member to serve as a proctor who would supervise and support students while they were using the online course. The proctor did not have to be a mathematics teacher and was not required to provide instruction.
4. The online Algebra I course had to serve as AR students' only grade 8 mathematics course.

All of the treatment schools fulfilled these requirements.³⁵

Formation of the Online Algebra I Classes

As noted in chapter 2, 242 students in the 35 treatment schools were assigned to 10 online sections. Of these course participants, 211 (87%) students were identified by their schools before random assignment as algebra ready. In the fall of the study year, schools were allowed to identify additional students for the course. A total of 31 N–AR students (4% of the 782 N–AR students in treatment schools) enrolled in the course.

³⁵ There were reports of brief, periodic interruptions in Internet access in a small number of schools, and a few schools experienced a delay in assigning computers to students.

Each online teacher taught one or two sections, with an average of 24 students per section (table 3-1). Eight of the 10 sections included students from multiple schools, but all the online course sections were composed of students from either Maine or Vermont—no section included students from both states. There were 7 online sections with 173 students from Maine and 3 sections with 69 students from Vermont. These sections were formed by the study’s director of implementation and Class.com, primarily by grouping schools that had a similar amount of time per day for grade 8 mathematics (for example, 50 minutes every day versus a double block three times a week) and other scheduling similarities.

Table 3-1. Numbers of Students and Schools per Online Course Section

Section	Number of schools	Number of AR students	Number of N-AR students	Total number of students	Teacher
1	4	13	0	13	E
2 or 3	5	36	11	47	C and G
4	5	25	5	30	G
5 or 6	7	42	0	42	B and D
7 or 10 ^a	8	40	9	49	H and F
8 or 9 ^a	6	55	6	61	A
Total	35	211	31	242	8

AR is algebra ready. N-AR is not algebra ready.

Note: Sample includes 35 schools and 242 students. Because six students in section 3 did not receive their computers until several weeks into the academic year, Class.com originally assigned them to a separate course section taught by teacher G. After several months, teacher G requested that these students be merged into an existing section (section 3) because it was more efficient to supervise the work of one larger section than two smaller sections. Therefore, the 11 sections collapsed to 10 sections midway through the school year.

a. Sections with fewer than four schools or students were aggregated to protect the confidentiality of participating schools and students.

Source: Study team records and online course activity archival data.

Mode of Instruction and Content of the Online Algebra I Course Offered to AR Students in Treatment Schools

The following sections describe the implementation of the online Algebra I course in treatment schools in terms of the mode of instruction (including fidelity of implementation) and the content of the course (including coverage and course completion rates).

Mode of Instruction

Mathematics instruction for AR students in treatment schools had three primary components: the online Algebra I course, the online teacher, and the on-site proctor.

Unlike a traditional course, in which the primary mode of instruction is for a teacher to provide information directly to students, the primary mode of instruction for students taking the online Algebra I course was their interaction with the materials and activities available online. Class.com delivered the online course activities through Moodle, an open source course management system.

The online course presents material as units, lessons, and topics. Each topic is presented to students in the form of an electronic, interactive textbook. The textbook includes computerized direct instruction; guided practice (“your-turn” problems) and practice problem sets, both with

automated feedback; and quizzes and exams that provide immediate scores. Other activities include demonstrations of content materials, audio clips, interactive applets that present questions and guided solutions, a messaging feature through which students can send and receive messages from the online teachers, and a discussion board to which students can post questions or comments.

Each lesson within a unit is divided into sets of topics that are designed to be completed within a 50- to 55-minute period. The following are examples of typical mathematics activities that students encountered daily. The examples are drawn from the Slope-Intercept topic of the Other Forms of Linear Equations lesson in the Linear Equations unit (figure 3-1).

- The topic begins with static text, which students read. Rollover definitions are available for important terms. These terms appear in bold, underlined, blue type; the definition appears near the term when users place the cursor over the term (figure 3-2).
- As students progress through a topic, the material they encounter alternates between static text and “chalktalks,” short videos with audio that serve as mini-lessons. The audio portion of the chalktalks is a voiceover describing the solution steps of the problem presented (figure 3-3).
- Computer-scored “your-turn” problems and practice set problems are a primary component of the course. Students receive immediate feedback on whether their answers are correct or incorrect by selecting “Check My Answers.”³⁶ Figure 3-4 presents practice set problems. It shows how the scoring appears to students when they check their answers and how an explanation is presented when they select “please explain.”
- Interactive activities are sometimes paired with problem sets or content pages. The complexity and instructional purpose of the interactive applets vary and can consist of an interactive demonstration, guided questions, or open-ended prompts. In the interactive activity within this topic, students must graph two points to create a line before proceeding with the first set of practice problems (figure 3-5).
- Quizzes (both practice and graded) are included at the end of each lesson; exams (practice and graded) are given at the end of each unit. Quizzes and exams consist of item sets randomly generated by the course management system from Class.com’s item banks.

³⁶ It is the responsibility of students to complete the problems, check their work, and follow up if they do not understand something; the online course management system does not record whether students attempt the practice problems or record their scores.

Figure 3-1. Unit Menu: Lessons and Topics

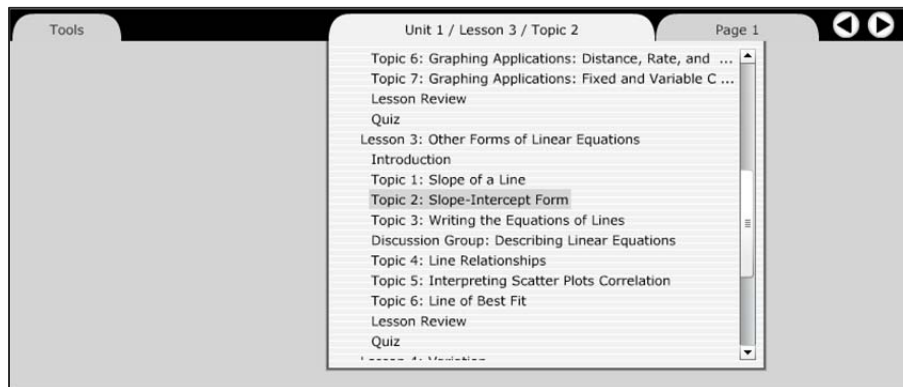


Figure 3-2. Static Text with Hyperlinked Terms and Definitions

A screenshot of a software interface showing static text. The title bar reads "Unit 1 / Lesson 3 / Topic 2" and "Page 1". The text is titled "Slope-Intercept Form" in red. The main text reads: "Have you noticed in the graph of a linear equation (a straight line) that if the line is not vertical, there is a point where the line crosses the y-axis? This point is called the [y-intercept](#) and is a very important point in the graphing of a line. There is also a corresponding point on the x-axis called the [x-intercept](#), where the graph of a line that is not horizontal will cross the x-axis. Let us look at a couple of lines and note these two points. Let's look at some examples and then you can try one on your own." A yellow callout box on the right contains the text: "The x-intercept of a line is the point where the line crosses the x-axis. It is found algebraically by substituting $y = 0$ into the equation."

Figure 3-3. "Chalktalk" Short Videos

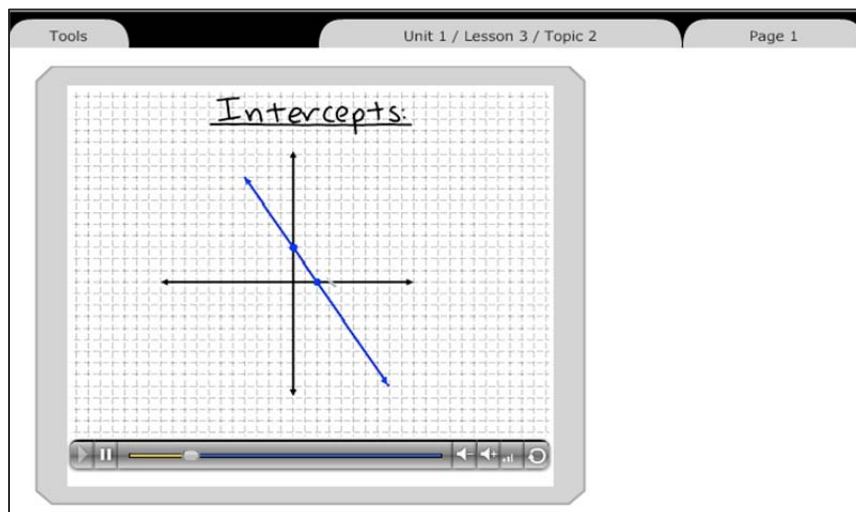


Figure 3-4. Practice Set Problems and “Check My Answers” Feature

The screenshot shows a math practice interface with a header bar containing 'Tools', 'Unit 1 / Lesson 3 / Topic 2', and 'Page 1'. Below the header, there are four numbered problems:

1. On line $\overline{CD}$, the y-intercept is .
2. The ordered pair for the y-intercept is (,).
3. The x-intercept is .
4. The ordered pair for the x-intercept is (,).

Below the problems is a red checkmark icon and the text '[Check My Answers]'. The interface then shows the results of the answers:

1. On line $\overline{CD}$, the y-intercept is ✓.
2. The ordered pair for the y-intercept is (✓ , ✓).
3. The x-intercept is ✗.
4. The ordered pair for the x-intercept is (✗ , ✓).

Each incorrect answer has a red 'X' and a '[Please Explain]' button. An 'Answer Window' is open, showing the URL http://content.class.com/c3_content/lor/mathematic and the text: 'The line crosses the x-axis at 2. Therefore, the x-intercept = 2.'

Figure 3-5. “Your Turn” Interactive Exercises

The screenshot shows a 'Your Turn' interactive exercise. The header bar contains 'Tools', 'Unit 1 / Lesson 3 / Topic 2', and 'Page 1'. Below the header, there is a red banner with the text 'Your Turn' and a red arrow icon. The main text reads: 'Draw the graph of the line containing the following points: C (4, -4) and D (1, 2).'

Below the text is a coordinate plane with a grid. The x-axis and y-axis both range from -10 to 10, with major grid lines every 5 units and minor grid lines every 1 unit. The origin is labeled '0'. The x-axis is labeled 'x' and the y-axis is labeled 'y'. A blue box on the left contains the text: 'Move your mouse over the graph and plot each coordinate from the table by using the red circular target and clicking on the desired coordinate.'

Below the blue box is a 'Reset' button.

For each topic, students typically encounter an average of 7 web pages of static and interactive text, 1 or more chalktalks, 1 or more interactive activities, 8 “your-turn” problems, and 10 practice set problems. Topics conclude with a summary of key ideas presented and practiced during the topic set. The Moodle online course management system gives students the means to communicate with the online teacher (described in more detail in the following subsection) and to access information on their grades, including the cumulative percentage correct and the percentage of correct answers on all quizzes and exams, and copies of all their online communications with the online teacher.

To engage in the online course’s instructional activities, students need to log in to the online course. As described in chapter 2, student login activity is archived by the course management system and analyzed to describe students’ and online teachers’ activity in the online course. The study team observed the online course instruction and interactions between online teachers and their students using archived data provided by the online course provider. Specifically, for each of the 10 online course sections, the study team randomly selected one school day each month (October–May) and downloaded all online activity over a 24-hour period. Researchers collected 24-hour samples of archived data once a month for eight months for each of the 10 course sections, for a total of 80 observations (eight per section). The analysis of these data shows that on average, 75% of students in each online course section logged into the course during the 24-hour observations. Students were expected to log into the online course at least once during their daily mathematics practice.³⁷

The Role of the Online Teacher

This section describes the expectations of the online teachers and presents data describing their actual activities during the course of the study year. According to Class.com, the role of online teachers is to grade written assignments, review students’ scores on quizzes and exams, coach and motivate students, conduct online discussions, and demonstrate concepts and processes. Online teachers work asynchronously with students, meaning that they are typically not online at the same time as students. During the two-day training workshop for the online teachers, Class.com demonstrated the means through which teachers could use the online course management system to communicate with students and monitor their progress in the course. In the training, Class.com indicated that online teachers should monitor students’ progress on a daily basis and communicate with students on most days.

Monitoring Progress. Class.com’s stated expectation for the online teachers is that they log in to the course management system daily to monitor student progress. Although the course management system gives teachers several types of information on student performance and progress through the course, some aspects of course progression are not accessible to teachers. Teachers can see the unit on which students are working, but they do not have access to information on where a student is within the unit (that is, which lesson or topic). Teachers do not have information on students’ completion of or scores on problem sets within lesson topics. Teachers do have a record of students’ scores (percent correct) on graded quizzes and exams, and

³⁷ The rate at which students did not log on to the course during the observation period is in line with anecdotal reports from Class.com that students missed a number of days, particularly in the second half of the year, because of grade- or schoolwide activities.

they can see which items from the test bank were included in quizzes and exams and which problems students answered correctly and incorrectly on quizzes and exams.

To assess the regularity with which online teachers logged in to the course to monitor student activity, the study team analyzed the online course activity archived by the course management system and tallied whether each section's online teacher logged on to the course management system at least once during each 24-hour observation period. On average, online teachers logged in during 96% of the observation periods, suggesting that they were logging on to the course daily. The study team also examined the 24-hour observations to record teachers' activities while online. Although online teachers were provided explicit guidance to monitor student login and general course activity on a daily basis, section teachers monitored student login activity at least once during the observation period in only 70% of the observed sessions. Online teachers were not provided explicit guidance about the frequency with which they should examine student grades (by going to the "student gradebook"). They were observed to do so in 43% of the observation periods.

Communicating with Students. Online teachers are expected to read and respond to student messages daily and to send messages (through the course management system) to all students daily as they review student work. Online teachers can communicate with students by using the online messaging system available through Moodle and review records of these communications.³⁸ In addition to sending messages to students, online teachers are expected to reply to any student-initiated messages within 24 hours to ensure that students receive the reply the next time they are scheduled to log in to the online Algebra I course. Online teachers can also use the course home page to make announcements to students in their sections or post additional materials, such as review sheets or additional work to support student mastery of a particular concept.

To assess the frequency and regularity of teacher communications with individual students, researchers counted the number of teacher-to-student messages and then coded the content of the message and identified whether it was course related. Messages were coded as providing administrative feedback (for example, grades, the pace at which a student was progressing through the course) or mathematics content (for example, encouraging understanding reflection or critical thinking; providing constructive feedback; and using incorrect answers as learning opportunities). The number of messages are assumed to be related to the number of students in each section. Therefore, rather than report the number of online messages sent during the observations, researchers first reported the percentage of observations during which teachers sent at least one message and then reported the average percentage of students in the section who received messages.

Online teachers sent at least one message to a student in 91% of the observations; on average, 27% of students in each section were recipients of these messages. Messages included administrative feedback, mathematics content feedback, or other content, such as greetings.

³⁸ All online communication between students and teachers occurred only through the online course's messaging system.

Online teachers sent at least one message to a student that contained administrative feedback in 51% of the observations (an average of 4.1 of the eight observations per section). On average, teachers directed this feedback to 13% of the students in the section.

Online teachers sent at least one message to a student that contained mathematics content in 18% of the observations (an average of 1.4 of the eight observations per section). On average, teachers directed these messages to 3% of the students in the section.

Students could also initiate communication with their online teacher. At least one student asked the online teacher a question through the course messaging system in 81% of the observed sessions. On average, 10% of students in a section sent a message to their teacher with a question. In observations where students asked questions, the online teacher replied to this question within 24 hours an average of 96% of the time.

In summary, online teachers logged in to the course at least once a day to monitor students' activity or progress, and they communicated directly with approximately one-fourth of students every day. Communications with explicit mathematics content were infrequent (more frequent were messages containing administrative feedback). When a student contacted the online teacher directly, the teacher almost always replied within 24 hours.

The Role of the On-Site Proctor

Every treatment school provided an on-site proctor, who was available to students during the designated class periods.³⁹ The role of the proctor was to ensure that students had access to the required technology, proctor exams, supervise students' behavior, serve as a personal contact for students and parents, and serve as the liaison between the online teacher and the school or parents. Because their role did not include providing mathematics instruction, proctors did not need to be qualified mathematics teachers. The schools selected the staff members who served as proctors.

Before the beginning of the 2008/09 school year, the proctor and a technical support staff member from each treatment school participated in a one-day training. Class.com staff delivered the training sessions in three locations (two in Maine and one in Vermont). The six-hour training sessions covered the structure of the online course and provided hands-on training on operating the courseware, including viewing students' progress through the course, accessing their assessment scores, and using the embedded communication tools. The training also suggested methods for helping students keep track of their own progress. All 35 treatment schools sent at least one representative to the training, with 33 schools sending their proctor and 27 schools sending a technology support staff member.

Data from the weekly proctor logs indicated that in 28 of 35 treatment schools (80%), the proctor was the grade 8 mathematics teacher. In the remaining schools, the proctors were other mathematics teachers in the school, the principal, or the education technology specialist.

In more than 90% of treatment schools, proctors had other responsibilities during the time they were supervising the online students. In 69% of schools (24 of 35), proctors were teaching another class while proctoring the online course). In other schools, students accessed the course

³⁹ Some schools had more than one proctor.

from their “own” separate classroom, the library, the computer lab, or a combination of a classroom and another space in the school.

Although the role of the proctor as defined for the study did not include providing mathematics instruction, the proctors (80% of whom were also grade 8 mathematics teachers) were a source of instructional support for online students. Proctors’ weekly logs reveal that they spent an average of about 50 minutes a week answering students’ algebra-related questions and 10–14 minutes a week answering nonalgebra mathematics questions (table 3-2). They also assisted students with technical issues and communicated with the online teachers.

Table 3-2. Proctor Activities Associated with the Online Course

Activity	Fall (November– December 2008)	Winter (January– March 2009)	Spring (April – June 2009)
	Minutes per week		
Answering students’ algebra-related questions	54.2 (44.1)	53.6 (55.8)	50.1 (54.6)
Answering students’ nonalgebra mathematics questions	12.8 (14.7)	15.5 (28.6)	12.3 (28.0)
Providing students with technical support	10.2 (17.0)	7.9 (9.7)	8.0 (13.3)
Communicating with online teacher	5.2 (4.9)	6.2 (4.0)	6.2 (4.9)
Communicating with Class.com technical support	0.8 (3.3)	0.7 (2.6)	1.0 (1.9)
Communicating with in-school technical support staff	2.1 (3.4)	1.5 (2.2)	2.5 (5.8)

Note: Sample includes 35 schools and 38 proctors. Figures in parentheses are standard deviations.

Source: Proctor logs.

Course Content

The Class.com course is divided into two parts, Algebra 1A and Algebra 1B, with each part designed to be equivalent to a semester in a traditional middle or high school Algebra I course. Algebra 1A has five units, which address symbols and number properties, functions and equations, equations and problem solving, inequalities and absolute value, and polynomials. Algebra 1B has four core units, which focus on functions and relations, systems of equations and inequalities, the simplification of rational and radical expressions, and quadratic equations. Two additional units focus on statistics and probability.⁴⁰

According to Class.com, students need 32–34 weeks (160–170 days) to complete Algebra IA and IB, assuming 40–50 minutes of instruction each day. Both Maine and Vermont mandate a 175-day school year for grade 8 students, which is sufficient time to complete Algebra IA and IB according to the Class.com schedule.

⁴⁰ Appendix C provides detailed information on the content of each portion of the course.

In both states, state standards for grade 8 mathematics include algebraic concepts that overlap with many of the topics in the Class.com curriculum; however, neither state has specific content standards for Algebra I. The study team compared the mathematics content in the Class.com course with the content of two Algebra I textbooks in use in Maine and Vermont.⁴¹ As described in appendix C, the Class.com course was well aligned with these curricula. Additional information on the structure and content of the online course is provided in appendix C.

Online Course Completion Rates

An important aspect of the course content in the intervention is the amount of the course students actually completed. The course offered by Class.com is designed as a full-year course. The expectation is that students can move slightly ahead or spend extra time covering topics if necessary, but the course is not intended to be self-paced.

The pace at which students actually progressed varied, as did rates of course completion. About 43% of AR students completed all nine units of Algebra IA and IB, and another 39.3% completed all of IA and some of IB (six, seven, or eight units) (table 3-3).⁴² A student “completed” a unit by passing the respective end-of-unit test with a score of 60% or higher. The study team defined passing as 60% or higher because the standard criterion for “passing” varied across participating schools, some setting the passing criterion at 60% and others at 70%. The 60% threshold was chosen so that students would not be held to higher standards by the course than was typical for their school. The only significant predictor of course completion was baseline mathematics achievement, as measured by the study-administered Promise Assessment: students who scored above the mean on the study-administered pretest were more likely to complete the online algebra course than student who scored below the mean (table 3-4).

Table 3-3. Number of Online Algebra I Course Units Completed by AR Students

Portion of Online Algebra I Course Completed	Number of units completed	Percentage of students
Some but not all of IA	Fewer than 5	11.9 ^a
All of IA	5	6.2
IA and some but not all of IB	6	16.6
	7	11.8
	8	10.9
All of IA and IB	9	42.6 ^b

Note: Sample includes 35 schools and 211 AR students. Algebra IA has five core units and Algebra IB has four core units. Students who completed nine core units completed Algebra IA and Algebra IB. There was variation in how much of the course students completed within and across the 10 online sections.

a. Number of students who completed fewer than five course units included 9 (4.3%) of AR students who withdrew from the online course.

b. Thirty-one percent of the 211 AR students also completed the two additional units on statistics and probability beyond Algebra IA and IB.

Source: Study team records based on online course activity archival data.

⁴¹ The two textbooks are *Algebra: University of Chicago School Mathematics Project* (McConnell, 2002) and *Glencoe Algebra 1* (Holliday et al. 2005).

⁴² Thirty-one N-AR students were also enrolled in the on-line course in treatment schools, however because all impact analyses take an intent-to-treat rather than a treatment-on-the-treated approach, these students were excluded from descriptive statistics of course completion and inferential statistical analyses.

Table 3-4. Online Course Completion Rates, by Student Characteristics

Characteristic	Total students	Number completing course	Percent completing course	p-value
Eligible for free or reduced-price lunch, special education services, or limited English proficiency ^a	78	28	36	0.061
Not eligible for free or reduced-price lunch, special education services, or limited English proficiency	131	62	47	
Female	102	46	45	0.345
Male	108	44	41	
Racial/ethnic minority	12	5	42	0.697
White	193	85	44	
Below mean on Grade 7 state mathematics assessment ^b	106	41	39	0.398
Above mean on Grade 7 state mathematics assessment	104	49	47	
Below mean on Fall 2008 pretest (Promise Assessment) ^b	100	32	32	0.015
Above mean on Fall 2008 pretest (Promise Assessment)	110	58	53	

AR is algebra ready.

Note: Sample includes 35 schools and 211 AR online course participants. Tests of significance were conducted using a hierarchical generalized linear model that assumed a Bernoulli sampling distribution and logit link function. All models were adjusted for nesting of students within schools.

a. The three groups of students were aggregated into a single group for analysis and presentation in order to protect student confidentiality.

b. AR students enrolled in online course only.

Source: Study team records based on online course activity archival data. Data for demographics and state mathematics achievement are from the Maine state department of education and supervisory unions in Vermont (2008).

Mode of Instruction and Content of the Regular Mathematics Courses Offered to Students in Treatment and Control Schools

The study team also collected data on the mathematics instruction received by students taking the regular grade 8 mathematics classes in treatment and control schools. In treatment schools, these were the N-AR students, and in control schools, these were both AR and N-AR students. The data sources included classroom materials, the teacher survey, class rosters, and site visits by members of the study team.

Mode of Instruction for General Mathematics Courses in Treatment and Control Schools

Site visits confirmed that the predominant mode of instruction in grade 8 mathematics classrooms in the treatment schools (that is, the courses provided to the N-AR students in treatment schools) was face-to-face delivery of content. None of the primary general mathematics curricula in treatment schools was computer based; computers were used only to supplement instruction in some classrooms. Analyses of classroom materials indicated that text-based programs were used in grade 8 classes in all 29 classrooms that provided data. The most commonly used program was Pearson-Prentice Hall *Connected Mathematics* (9 schools) followed by McDougal Littell *Math Themes* (5 schools) and Glencoe *Mathematics Course 3* (5 schools). Other textbooks included Saxon *Course 3 (Algebra 1/2)* and Foresman-Wesley *Math*.

The main mode of instruction in control schools (delivered to both AR and N-AR students) was also face-to-face, teacher-led instruction. The two most commonly used grade 8 mathematics programs in control schools were *Connected Mathematics* (9 schools) and McDougal Littell *Math Themes* (8 schools). Other textbooks included Saxon *Course 3 (Algebra 1/2)*, Glencoe *Mathematics Course 3*, Glencoe *MathScape*, Pearson/Prentice Hall *Algebra I*, Holt *Algebra I*, and Foresman-Wesley *Math*.⁴³

Content of General Mathematics Courses in Treatment and Control Schools

Classroom materials were analyzed to compare the content of the general mathematics courses offered in treatment and control schools. Classroom materials included the name of the textbook used and any of the following that were available: course syllabi, curricular pacing guides, annotated tables of contents of mathematics textbooks, and course exams. Mathematics content experts on the study team coded the general grade 8 class materials, indicating the degree to which they focused on algebraic content (25%, 50%, 75%, and 100%). The coders used just four categories because detailed pacing information was available from too few schools to estimate more precisely (by, for example, the number of weeks spent on algebra).

The course content delivered to N-AR students in the treatment schools included both general grade 8 mathematics content and algebra content. Among the treatment schools that provided classroom materials for the general grade 8 mathematics class (from which the online Algebra I course participants had been removed), 79% had a curricular focus on algebraic content of 50% or higher. Nearly one-third (31%) had a focus of 75% and 0% of treatment schools had a general grade 8 mathematics class with an algebraic content focus of 100% (as did the online Algebra I course offered to AR students in treatment schools).

Among the control schools that provided grade 8 mathematics classroom materials, over 90% had a curricular focus on algebraic content of 50% or higher. More than one-third (35%) of the control schools had a focus on algebra of 75%, and 16% had an algebraic focus of 100%. Based on the review of state content standards and recruitment discussions with state and local educators, researchers expected that the general mathematics courses in control schools would include a substantial amount of algebraic content. However, without a separate comparison group of schools that was unaware of the study, there is no way to know whether the amount of algebra in the study control schools represents what is typical or whether the amount of algebra offered was affected by participation in the study.

The target sample for the study was schools that did not offer a stand-alone Algebra I course to all of their AR students (schools that offered a separate Algebra I course to a limited number of AR students were considered eligible for the study).⁴⁴ The study team did not expect any of the control schools to offer a formal Algebra I course to all of their AR students. However, analysis of classroom materials indicated that in 7 control schools, most (94%) of AR students took a separate Algebra I course at their middle school or the local high school. In total, 45 AR students

⁴³ Further information about the number of schools that used each textbook and links to more information about each textbook are provided in appendix B, table B-1.

⁴⁴ Schools that provided Algebra I to grade 8 students in a limited way (by, for example, allowing students to take the course at the high school when scheduling worked out) were eligible for this study, because they did not offer the course in a way consistent with the goals of the study: to broaden access to Algebra I for all AR students in the school.

at control schools took Algebra, representing 20.3 percent of the total sample of AR students in control schools.

Other Programmatic Features of the Intervention and Business as Usual Mathematics Instruction

In addition to the mode of delivery and mathematics content, adoption of the online course in study schools introduced four potential differences from the business-as-usual grade 8 mathematics programs: qualifications of teachers, staffing intensity, class size, and ability grouping of students. In the following sections, we describe the implementation of (1) the online course delivered to AR students in treatment schools, (2) the regular mathematics classes (delivered to N-AR students) in treatment schools, and (3) the regular mathematics classes delivered to both AR and N-AR students in control schools in terms of these four aspects.

Teacher Qualifications

As reported in Chapter 2 (see Table 2-12), a significantly larger proportion of online teachers (100%) were certified in secondary mathematics than the regular teachers in treatment schools (39%) and control schools (37%) ($p = 0.003$ and 0.003 , respectively). In addition, significantly more online teachers held master's degrees in mathematics education or mathematics than did regular teachers in treatment schools (38%) and control schools (20%) ($p = 0.017$ and 0.001 , respectively).⁴⁵ The online teachers had taught Algebra I for an average of 9.5 years, significantly more than the average for regular teachers in treatment schools (2.3 years) and in control schools (3.7) ($p = 0.001$ and 0.008 , respectively). The online teachers also had significantly more years of total teaching experience (22.9 years) than did the regular teachers in treatment schools (14.8 years) and in control schools (14.7) ($p = 0.034$ and 0.043 , respectively).

Staffing Intensity

To capture staffing intensity, researchers used two measures: the number of adults associated with the students taking the online course and the overall grade 8 student to teacher ratio.

All students taking the online course had access to both an online teacher and an in-class proctor; therefore, two adults were available to support each student enrolled in the online course. Because the proctor was also the regular grade 8 mathematics teacher in 80% of the treatment schools, both adults were qualified to provide mathematics instruction (albeit not necessarily Algebra I instruction in the case of all proctors). N-AR students in treatment schools had access to one mathematics teacher, yielding a staffing intensity of one teacher per N-AR grade 8 student. Accounting for the online teacher and online course proctors who were not also grade 8 mathematics teachers, the student-teacher ratio for all students (AR and N-AR) in treatment schools was 10.1 to 1.⁴⁶ Students in control schools also had access to one mathematics teacher; the student to teacher ratio was 18.8 to 1.

⁴⁵ To maintain confidentiality of the participants, the number and percentage of online teachers with master's degrees were suppressed for presentation purposes.

⁴⁶ The student-teacher ratio was calculated by dividing the total number of grade 8 students by the total number of adults per school involved in grade 8 mathematics. In treatment schools, the number of adults equals the sum of the number of grade 8 mathematics teachers, the online teacher, and online proctors who were not also grade 8 mathematics teachers. In control schools, the number of adults is the number of grade 8 mathematics teachers.

Class Size

For the online class, two measures of class size were used: the number of students per online section and the number of online students per school. The average number of students per online section was 24 (standard deviation = 6.0).⁴⁷ The average number of online students per school was 6.9; however, not all online students participated in the online course at the same time in the same physical space. The average number of online students who participated in the course at the same time and in the same space per treatment school was 3.9 (standard deviation = 1.9).

The average class size of the general grade 8 mathematics classes in treatment schools (which did not include students taking the online Algebra I course) was 9.98. The average class size reported by grade 8 mathematics teachers in control schools was 11.69. The difference in the average class size of general grade 8 mathematics classes in treatment and control schools was not statistically significantly different ($p = 0.259$).

Ability Grouping

Nearly all of the students (97%) in treatment schools identified by their schools as algebra ready before the start of the study enrolled in the online course, and most of the online algebra course participants (87%) were AR students. Analyses of mathematics achievement scores confirmed that the students identified as AR were higher achieving than their N-AR peers who were not identified for the course (see chapter 2 and appendix A, figures A-2 and A-3). Therefore, it is safe to conclude that in treatment schools, AR and N-AR students were separated by ability level, as expected.

However, AR and N-AR students were often not segregated into different physical classes in treatment schools. Site visits to treatment schools noted that online students sat in the general grade 8 mathematics classroom to take the online course in about 69% of schools.

To capture the extent of ability grouping in control schools, researchers used class rosters and teacher survey reports to gauge the extent to which AR and N-AR students were assigned to the same teachers and were in the same sections. Of the 33 control schools, 18 (55%) had classes in which AR and N-AR students were integrated, 11 (33%) had classes in which students were separated by ability, and 4 (12%) had only AR students.

Researchers surveyed teachers of the regular mathematics classes in treatment and control schools to understand their approaches to ability grouping and differentiating instruction. Although it appeared that students in the general grade 8 classrooms in treatment schools were on average lower in ability level and more homogenous than they would have been had the AR students been enrolled in their class, about 80% of teachers reported differentiating their instructional practices to a moderate or great extent. In control schools, about 75% of teachers in control schools reported differentiating their instructional practices to a moderate or great extent.

When asked about giving students with higher ability accelerated material, such as Algebra I content, about 45% of the regular mathematics teachers in treatment schools reported doing so, compared with about 68% of the teachers in control schools. This difference was statistically significant ($p = 0.024$).

⁴⁷ This average includes both AR and non-AR students enrolled in the online course.

Summary of Key Implementation Findings

The six programmatic features identified in chapter 1 were used to describe mathematics instruction in the treatment and control classrooms (table 3-5).

Table 3-5. Programmatic Features of Intervention and “Business as Usual” Grade 8 Mathematics Course in Study Schools

Feature	AR students in treatment schools	N–AR students in treatment schools	AR and N–AR students in control schools
Mode of delivery	Web based	Face to face	Face to face
Course content	Algebra I	79% of schools’ curricula emphasized algebraic concepts 50% or more of the time	Over 90% of schools’ curricula emphasized algebraic concepts 50% or more of the time; 20% of AR students took separate Algebra I course
Teacher qualifications	100% certified to teach secondary math	44% certified to teach secondary math	43% certified to teach secondary math
Staffing intensity	2 staff per student (online and proctor); student to teacher ratio of 10.1 to 1	1 teacher per student; student to teacher ratio of 10.1 to 1	1 teacher per student; student to teacher ratio of 18.8 to 1
Class size (students per class)	3.9	10.0	11.7
Ability grouping	High-ability students grouped together	Non-high ability students grouped together; 45% of teachers reported accelerating instruction for high-ability students	Students grouped together in 58% of schools and separately in 33% of schools (12% of schools had only AR students); 68% of teachers reported accelerating instruction for high-ability students

AR is algebra ready.

Analyses of archived data from the online course management system and data from the weekly proctor logs showed that the types and amount of communication between online course participants and their teachers and proctors did not match the initial expectations for the intervention. Online teachers did not communicate directly with all of their students about the course on a daily basis. The on-site proctor’s role was not intended to include mathematics instruction, but proctors reported that they spent approximately 50 minutes a week answering students’ questions about the mathematics content of the online course.

The content of the online course was typical for an Algebra I course, and participating students varied in the amount of the course content they completed. The course completion rates indicate that 43% of AR students who participated took a “full” Algebra I course, and most (more than 80%) completed more than half the course.

The general mathematics classes in control and treatment schools also included considerable Algebra I content, especially for AR students in control schools. In the control schools, 20% of AR students took a full Algebra I course during the year, and AR students in over 90% of the control schools that provided course materials received mathematics instruction that had a curricular focus on algebra content of 50% or more.

In terms of teacher qualifications, 100% of online teachers were certified in secondary mathematics, compared with 41% of grade 8 control teachers and 39% of treatment teachers. The staffing intensity was higher in treatment schools than in control schools, because students in the online course had access to both their online teacher and a proctor (who was often the grade 8 mathematics teacher). Students in face-to-face classes in both treatment and control schools had access to only the regular grade 8 mathematics teacher. Student to teacher ratios in treatment and control schools reflect these differences: the student to teacher ratio was 10.1 to 1 in treatment schools and 18.8 to 1 in control schools. Although an average of 6 AR students per treatment school were placed into the online course, the average class size of general grade 8 mathematics classes in treatment and control schools was not significantly different.

With respect to ability grouping, removing the AR students from general grade 8 treatment classrooms and placing them in the online course created ability groupings (AR and N-AR students were enrolled in different courses). However, approximately 80% of the online course proctors were also the grade 8 mathematics teacher, and AR and N-AR students sat in the same physical classrooms in almost 70% of treatment schools. In 26 of the 31 control schools that provided data, AR and N-AR students were integrated in the same grade 8 mathematics classes. However, several forms of within-class ability grouping occurred in these classrooms. In many cases, instruction was differentiated, with AR students receiving more instruction in Algebra I content than N-AR students. Teachers in control schools (who taught both AR and N-AR students in the same classes) were significantly more likely to report giving higher-ability students accelerated material than teachers in treatment schools (who taught N-AR students only).

Descriptive analyses from multiple data sources indicate that the online course was implemented as intended in the 35 treatment schools. The course was the only mathematics course taken by the AR students during that academic year. Students were provided with courseware that was fully functional throughout the school year, the technology they needed to access the course from school (one-on-one access to a computer with a high-speed Internet connection), a class period for Algebra I online that met with the same frequency and duration as the regular grade 8 mathematics course, and an on-site proctor who supervised AR students during their mathematics class period. However, the online teachers monitored student progress and interacted with students less than expected, and the proctors provided more instructional support to the online students than expected. This information provides a backdrop for the next chapter, which focuses on the impact of the intervention on student achievement and high school coursetaking in mathematics.

Chapter 4 Impact of Online Algebra I on Primary and Secondary Student Outcomes

This chapter reports the results of the impact analyses conducted to address the study's six research questions. It examines the impacts of online Algebra I on AR and N-AR students after one year of implementation. Student outcome data, including an algebra and general mathematics posttest and planned coursetaking information, were collected from all grade 8 students in the participating schools in spring 2009. Follow-up coursetaking data were collected in spring 2010 for AR students only.

The results presented in this chapter are based on an intent-to-treat analysis that includes all grade 8 students in the study schools at the time of baseline data collection (fall 2008), except those who were withdrawn from the study by their parents (nonconsenters) or their schools ("not testable" students). Thus, the impact estimates reflect the impact of assignment to treatment condition.

The impacts were estimated using a multilevel regression model that uses all available observations from the treatment and control groups, including information on baseline covariates. The means reported for students in both treatment and control schools are the model-adjusted means, controlling for gender, free or reduced-price lunch status, special education status, prior state mathematics test scores, and school-level blocking variables (state and school size).

For analyses of continuous variables (algebra and general mathematics posttest scores), impact estimates are presented in their original metric and as Hedges' g effect sizes.⁴⁸ For analyses of categorical variables (coursetaking), the impact of the intervention is the difference in the probability of participating in an advanced mathematics course sequence by students in treatment and control schools. For these analyses, the difference between treatment and control groups is presented as the difference in the average model-predicted probability of participating in an advanced mathematics course sequence for AR students in each condition, controlling for prior mathematics achievement; demographic characteristics (gender, free or reduced-price lunch status, and special education status); and school-level blocking variables (state and school size).⁴⁹

For both types of analyses, the tables report the standard error and p -value for each impact estimate. Some differences in group means or predicted probabilities could occur by chance. The standard error indicates the magnitude of the uncertainty about the true mean of each impact, given the number of schools and students in the analysis. The p -value indicates the chance of obtaining an impact the size of the estimated impact if in fact there were no true impact.

⁴⁸ Hedges' g calculations use a standard deviation that is pooled across the treatment and control groups (Hedges 1981). Variances for the treatment and control groups used in the calculation of effect sizes were adjusted to account for the within and between imputation variance in the multiply-imputed datasets (Rubin 1987; Shafer & Graham 2002).

⁴⁹ The predicted probabilities were calculated by first generating logit estimates at the treatment and control sample means (with all covariates grand mean centered) and then converting them into probabilities for the treatment and control groups separately. These group means and associated standard errors were generated in SAS using PROC GLIMMIX by requesting the LSMEANS output for the contrast for condition.

This chapter first presents the results of the analyses that tested the primary research questions, including the main impact results followed by a summary of primary findings and the sensitivity analyses that were conducted to test the robustness of the main results. It then presents the results of the analyses that tested the secondary research questions, including the main results and the results of sensitivity analyses. A fuller presentation of results for each impact model is provided in appendix D, including coefficients and standard errors for each predictor; corresponding odds ratios are also included for coursetaking outcomes. The results for all sensitivity analyses are presented in appendix E.

Primary Impact Analyses: Impacts on Algebra Scores and High School Coursetaking by AR Students

The results reported in this chapter are based on analysis of the AR student sample, where missing data were imputed using multiple imputation (see appendix F). All estimates are aggregates across all 10 multiply imputed datasets that account for variance between and within the imputed dataset. The analytic sample for the AR analyses includes 440 students enrolled in 68 schools (218 students in 35 treatment schools and 222 students in 33 control schools).

Algebra Scores at the End of Grade 8

A two-level hierarchical model with students nested within schools was used to estimate the impact of having access to an online Algebra I course on AR students' algebra assessment scores at the end of grade 8. To improve the precision of the impact estimates, researchers included students' prior state mathematics test scores and background characteristics (gender, eligibility for free or reduced-price lunch, and special education status) as covariates in the model. School-level covariates included blocking variables (state and school size dummy variables). Except for the treatment status indicator, all covariates were centered on the grand mean.

AR students in schools randomly assigned to offer the online Algebra I course scored higher on the algebra posttest than their counterparts in schools that did not receive the course (table 4-1). The average algebra score for AR students in treatment schools was 5.53 scale score points higher than the average score for AR students in control schools (effect size = 0.40).

Table 4-1. Impact of Online Algebra I on Algebra Scores of AR Students in Treatment and Control Schools

Mean in treatment schools (standard deviation)	Mean in control schools (standard deviation)	Estimated impact (standard error)	<i>p</i> -value	Effect size
447.17 (15.04)	441.64 (12.29)	5.53* (1.57)	0.001	0.40

AR is algebra ready.

* Two-tailed statistical significance. Because of a multiple comparison adjustment that accounts for two primary analyses, a *p*-value less than 0.025 is considered statistically significant.

Note: Sample includes 68 schools (35 treatment, 33 control) and 440 AR students (218 treatment, 222 control). The treatment group and control group means are the model-adjusted mean scores for AR students, controlling for all covariates in the impact model. The effect size was calculated using a pooled standard deviation of the outcome for AR students in treatment and control schools that incorporates both within and between imputation variance (*SD* = 13.78).

Source: Algebra scores on study-administered Promise Assessment posttest.

High School Coursetaking

A two-level hierarchical model that is appropriate for binary outcomes was used to estimate the effect of having access to online Algebra I in grade 8 on the likelihood of participating in an advanced mathematics course sequence in high school. The model used is a hierarchical generalized linear model that assumes a Bernoulli sampling distribution and logit link function (Raudenbush and Bryk 2002; McCullagh and Nelder 1989).

The outcome measure for this analysis is participation in an advanced course sequence, based on the grade 9 mathematics courses taken, grades earned, and the course planned for grade 10. Students were considered advanced if they took a course above Algebra I in grade 9, passed their grade 9 course with a grade of C or higher,⁵⁰ and enrolled in Algebra II or higher for grade 10.

The impact of the online course on the likelihood of participating in an advanced course sequence was assessed with a hierarchical generalized linear model analysis that, like the model used to estimate the impact on algebra scores, included student- and school-level covariates. At the student level, the model controlled for students' prior state mathematics assessment scores and demographic characteristics (gender, eligibility for free or reduced-price lunch, and special education status). At the school level, the model included the blocking variables (state and school size dummy variables) and the treatment status indicator. All covariates in the model (except the treatment status indicator) were centered on the grand mean.

The results indicate that AR students from schools randomly assigned to offer the online Algebra I course were significantly more likely to follow an advanced mathematics course sequence than their AR counterparts in schools that did not offer the course (table 4-2). Specifically, the average probability of participating in an advanced course sequence was 0.26 for AR students from control schools and 0.51 for AR students from treatment schools. The intervention yielded a difference in the probability of participating in an advanced course sequence of 0.25, meaning that AR students from treatment schools were nearly twice as likely to participate in an advanced mathematics course sequence as AR students in control schools.

Table 4-2. Predicted Probability of AR Students Participating in an Advanced Mathematics Course Sequence in High School

Treatment school (standard error)	Control school (standard error)	Difference in probability attributed to intervention	<i>p</i>-value
0.51 (0.07)	0.26 (0.05)	0.25*	0.007

* Two-tailed statistical significance. Because of a multiple comparison adjustment that accounts for two primary analyses, a *p*-value less than 0.025 is considered statistically significant.

Note: Sample includes 68 schools (35 treatment, 33 control) and 440 students (218 treatment, 222 control). Coursetaking patterns were coded as representing successful completion of a course above Algebra I in grade 9 and enrollment in Algebra II or a higher course in grade 10) or not. The probabilities are the average model-predicted probabilities, controlling for all covariates specified for the model.

Source: Coursetaking data collected from high schools AR study students attended in 2009/10.

⁵⁰ If students took more than one mathematics course in grade 9, they had to have earned a grade of C or better on the more advanced grade 9 course to meet this criterion.

Results of Sensitivity Analyses

A set of sensitivity analyses was conducted to test the robustness of these results (see appendix E, tables E-1 and E-8). For the analysis of algebra scores at the end of grade 8, the direction of the treatment effect did not change under several different models and assumptions. As noted in Chapter 2, there was a difference by condition on the study-administered pretest such that AR students in treatment schools had higher scores and spent more time on the pretest than AR students in control schools. As a result, sensitivity model E.2 demonstrates that the magnitude of the effect decreased when the post-random assignment study-administered pretest was used as the baseline measure of prior achievement instead of the state mathematics assessment scores (see appendix E, model E.2). To examine whether the treatment effect on algebra posttest scores could be partially or completely explained by time spent on the posttest, sensitivity model E.7 included posttest testing time as a covariate. Results confirmed that the effect of the intervention on AR students' algebra posttest scores was not explained by testing time (see appendix E, model E.7).

For the analysis of coursetaking, sensitivity models that controlled for the study-administered pretest as a baseline achievement covariate instead of the state mathematics scores but were otherwise identical yielded results different from those reported in the benchmark analyses. Using the benchmark model but controlling for the pretest instead of the state mathematics scores indicated that the effect of the intervention was not statistically significant ($p = 0.037$), using an alpha value of 0.025 that accounts for multiple comparisons (see appendix E, model E.9). The results of all other sensitivity analyses conducted for high school coursetaking were consistent with the main results reported in this chapter.

Secondary Impact Analyses

Impacts on General Mathematics Outcomes for AR Students

The primary focus of the impact of access to online Algebra I for AR students is on their algebra achievement at the end of grade 8 and subsequent high school coursetaking. A secondary outcome is their achievement at the end of grade 8 on a general mathematics test. A significant negative effect on this outcome could signal a potential down side of offering an online Algebra I course to AR students.

To test whether access to online Algebra I affected AR students' general mathematics scores, researchers used the same two-level model used to estimate the impact of online Algebra I on AR students' algebra scores. The results revealed no significant difference by condition (effect size = 0.14) (table 4-3).⁵¹

⁵¹ The lack of a significant difference does not definitively show that general mathematics scores for AR students in treatment and control schools were equivalent. It simply implies that the difference was not large enough to be distinguished from chance, given the size of the sample.

Table 4-3. Impact of Online Algebra I on AR Students' General Mathematics Scores at the End of Grade 8

Treatment schools (standard deviation)	Control schools (standard deviation)	Estimated impact (standard error)	<i>p</i> -value	Effect size
361.42 (24.79)	357.82 (25.43)	3.60 (2.80)	0.204	0.14

AR is algebra ready.

Note: Sample includes 68 schools (35 treatment, 33 control) and 440 students (218 treatment, 222 control). The treatment and control group means are the model-adjusted mean scores for AR students, controlling for all covariates in the impact model. Result is not statistically significant. The effect size was calculated using a pooled standard deviation of the outcome for AR students in treatment and control schools that incorporates both within and between imputation variance ($SD = 25.22$).

Source: General mathematics scores on study-administered Promise Assessment posttest.

Impacts on N–AR Students

Three secondary analyses were conducted to determine the impact of offering Algebra I online to AR students on N–AR students' outcomes. The three outcomes of interest were algebra and general mathematics scores at the end of grade 8 and planned grade 9 courses. For these analyses, N–AR students in treatment schools were compared with N–AR students in control schools.

Multiple imputation was used to create 10 datasets with missing data imputed (see appendix F). All estimates are aggregates across all 10 datasets that account for the variance between and within the imputed dataset. The analytic sample for the N–AR analyses included 1,445 students enrolled in 68 schools (744 in treatment schools and 701 in control schools; 4 control schools had no N–AR students).

Impact on Test Scores. A two-level hierarchical model with students nested within schools was used to estimate the impacts of online Algebra I on N–AR students' algebra and general mathematics assessment scores at the end of grade 8. The models used were identical to those described earlier for AR students for the same achievement outcomes.

The results of this analysis indicate no significant differences in algebra or general mathematics posttest scores between N–AR students in schools randomly assigned to receive the online Algebra I course and their N–AR counterparts in control schools (table 4-4). The impact of online Algebra I translates to an effect size of 0.06 on algebra scores and 0.02 on general mathematics scores, neither of which is statistically significant.

Table 4-4. Impact of Online Algebra I on N-AR Students' Algebra and General Mathematics Scores at the End of Grade 8

Subject area	Treatment schools (standard deviation)	Control schools (standard deviation)	Estimated impact (standard error)	p-value	Effect size
Algebra	430.76 (15.36)	429.80 (15.64)	0.96 (1.25)	0.443	0.06
General Mathematics	324.86 (28.42)	324.21 (30.04)	0.65 (2.41)	0.789	0.02

N-AR is not algebra ready.

Note: Sample includes 68 schools (35 treatment, 33 control) and 1,445 N-AR students (744 treatment, 701 control); 4 control schools had no N-AR students. Estimates were averaged across 10 multiply imputed datasets. The treatment and control group means are the model-adjusted mean scores for AR students, controlling for all covariates in the impact model. Results are not statistically significant. Effect sizes were calculated using a pooled standard deviation of the outcome for N-AR students in treatment and control that incorporates both within and between imputation variance ($SD = 15.50$ for Algebra and 29.39 for General Mathematics).

Source: Algebra and general mathematics scores on study-administered Promise Assessment posttests.

Impact on Planned Grade 9 Courses. Planned grade 9 courses for N-AR students were coded as 1 for intermediate (a course at or above Algebra I) and 0 for not intermediate (a course below Algebra I, such as Pre-algebra). To estimate the effect of offering online Algebra I (in grade 8) to AR students on N-AR students' probability of enrolling in Algebra I in grade 9 (as per an intermediate course sequence), researchers used a two-level hierarchical model for binary outcomes. The differences between students in treatment and control school were not statistically significant (table 4-5).

Table 4-5. Predicted Probability of N-AR Students Enrolling in Intermediate Mathematics Course Sequence in Grade 9

Treatment schools (standard error)	Control schools (standard error)	Difference in probability attributed to intervention	p-value
0.89 (0.04)	0.79 (0.06)	0.10	0.099

N-AR is not algebra ready.

Note: Sample includes 68 schools (35 treatment, 33 control) and 1,445 N-AR students (744 treatment, 701 control); 4 control schools had no N-AR students. Estimates were averaged across 10 multiply imputed datasets.

Probabilities are the average model-predicted probabilities, controlling for all covariates specified for the model. Result is not statistically significant.

Source: Planned courses indicated by study students at end of Grade 8.

Results of Sensitivity Analyses

A set of sensitivity analyses was conducted to test the robustness of these results (see appendix E, tables E-22 and E-27). With one exception, the effect of online Algebra I did not change under different models and assumptions. The analyses did not detect significant effects on AR students' general mathematics scores, on N-AR students' algebra or general mathematics scores, or the likelihood of enrolling in an intermediate course sequence in high school.

The one exception was for N-AR students' planned grade 9 coursetaking. One sensitivity analysis (model E.23, which uses complete case analysis instead of multiple imputation for missing data) revealed a statistically significant difference in favor of students in treatment

schools. Specifically, N-AR students from treatment schools were significantly more likely to enroll in an intermediate level grade 9 course than N-AR students from control schools ($p = 0.035$; see table E-27). The pattern was similar in the main analysis and the other sensitivity analyses, although the difference reached the level of statistical significance only in this analysis. Nevertheless, all of the sensitivity analyses (including this one) confirm that there were no significant negative effects of the intervention on AR students' general mathematics scores or on any of the N-AR students' outcomes.

Chapter 5 Exploratory Analyses of AR Students' High School Coursetaking

The main results in chapter 4 indicated that AR students in schools that offered an online Algebra I course to broaden access to Algebra I in grade 8 were significantly more likely to follow an advanced mathematics course sequence in high school than AR students in control schools. This chapter examines two exploratory questions intended to further understand the main results regarding AR students' coursetaking. It draws on data on AR students' planned grade 9 mathematics classes and their actual grade 9 and grade 10 mathematics course sequences.

Exploratory Research Questions

Exploratory Research Question 1: How does access to online Algebra I in grade 8 affect the likelihood that AR students sign up for advanced courses in grade 9? This exploratory analysis examines the impact of access to online Algebra I in grade 8 on students' planned grade 9 mathematics course enrollments, using data provided by schools at the end of grade 8. The outcome of interest is whether AR students in treatment schools are more likely than their counterparts in control schools to enroll in a course for grade 9 that if successfully completed, would place them on an advanced coursetaking trajectory.

Exploratory Research Question 2: How does access to online Algebra I in grade 8 affect the likelihood that AR students double up, or take more than one mathematics course a year, in grade 9 or 10? If access to online Algebra I in grade 8 enables students to enter high school farther along in the mathematics course progression, the intervention may decrease the probability that students double up on courses in grade 9 or 10. In addition to analyzing this question, researchers conducted a descriptive analysis of the coursetaking patterns that involve doubling up on mathematics courses. This analysis examined the different pathways by which students in treatment and control schools get on pace to complete Algebra II by the end of grade 10.

Results

Exploratory Research Question 1

To estimate the effect of having access to online Algebra I in grade 8 on the probability of enrolling in a course above Algebra I in grade 9, researchers employed the same two-level hierarchical generalized linear model used in the main analysis of high school coursetaking (see chapter 4).

The results of this analysis show that AR students in schools that offered the online Algebra I course were significantly more likely to register for an advanced grade 9 mathematics course than their AR counterparts in schools that did not offer the course (table 5-1). The average predicted probability of enrollment in an advanced mathematics course by AR students was 0.16 in control schools and 0.54 in treatment schools. The intervention thus yielded a difference in the probability of enrolling in a grade 9 course above Algebra I of 0.38, meaning that AR students in treatment schools were 3.38 times more likely than AR students in control schools to enroll in an advanced grade 9 course.

Table 5-1. Predicted Probability of AR Students Enrolling in Advanced Mathematics Course in Grade 9

Treatment schools (standard error)	Control schools (standard error)	Difference in probability attributed to intervention	<i>p</i> -value
0.54 (0.11)	0.16 (0.07)	0.38*	0.005

AR is algebra ready.

* No adjustments for multiple comparisons were applied for the secondary impact analyses, thus a *p*-value less than 0.05 is considered statistically significant.

Note: Sample includes 68 schools (35 treatment, 33 control) and 440 AR students (218 treatment, 222 control). Estimates were averaged across 10 multiply imputed datasets. Probabilities are the average model-predicted probabilities, controlling for all covariates specified for the model.

Source: Planned courses indicated by study students at end of Grade 8.

Exploratory Research Question 2

If access to online Algebra I in grade 8 enables students to enter high school farther along in the mathematics course progression, the intervention may affect the probability that students double up on full-year mathematics courses in grade 9 or 10. To address this question, researchers tested the impact of access to online Algebra I in grade 8 on the likelihood of taking two full-year mathematics courses in either grade 9 or grade 10 (that is, doubling up on mathematics coursework). The outcome for this analysis was a binary indicator of doubling up, where students were assigned a 1 if they doubled up in grade 9 or planned to do so in grade 10 and a 0 if they did neither. A total of 96 students—21% of the AR student sample across conditions—were coded as doubling up.

The analytic model testing whether the intervention impacted whether AR students doubled up in grade 9 or 10 was a hierarchical generalized linear model that accounted for the nesting of students within schools and included the same student- and school-level covariates as the impact models, with the exception of special education status.⁵² The results indicate that AR students from treatment schools were significantly less likely to double up on mathematics courses than AR students from control schools (table 5-2). Access to online Algebra I thus appeared to decrease the likelihood that students take more than one full-year mathematics course in grade 9, grade 10, or both grades.

⁵² Special education status was removed from the analytic model because no students who were deemed eligible for special education services doubled up in mathematics courses in either grade 9 or 10, causing mathematical errors in the estimation of the treatment effect.

Table 5-2. Predicted Probability of AR Students Doubling Up on Full-Year Mathematics Courses in Grade 9 or 10

Treatment schools (standard error)	Control schools (standard error)	Difference in probability attributed to intervention	<i>p</i>-value
0.10 (0.03)	0.23 (0.06)	−0.13*	0.033

AR is algebra ready.

* No adjustments for multiple comparisons were applied for the secondary impact analyses, thus a *p*-value of less than 0.05 is considered statistically significant.

Note: Sample includes 68 schools (35 treatment, 33 control) and 440 AR students (218 treatment, 222 control). Estimates were averaged across 10 multiply imputed datasets. Probabilities are the average model-predicted probabilities, controlling for all covariates specified for the model.

Source: Coursetaking data collected from high schools study students attended in 2009/10.

Taken together with the results of the main analysis presented in chapter 4, this exploratory analysis indicates that in addition to affecting whether students appear positioned to complete an advanced course sequence by the end of high school at the end of grade 9, offering Algebra I as an online course in grade 8 may also affect how they do so. Students with access to online Algebra I in grade 8 were less likely to double up on mathematics courses in grades 9 or 10 than their counterparts in control schools who, by and large, did not have access to Algebra I in grade 8.

Chapter 6 Summary of Key Findings

This chapter summarizes the key findings, identifies the study limitations, and suggests directions for future research.

Key Findings

Primary Questions and Results

The goal of this study was to measure the effects of broadening students' access to Algebra I by offering of an online course in schools that do not typically offer the course. The primary analyses assessed the impact of offering an online Algebra I course on AR students' algebra achievement at the end of grade 8 and their likelihood of participating in an advanced mathematics course sequence in high school. The results indicate that the intervention had a positive effect on both outcomes. On algebra achievement at the end of grade 8, AR students outperformed their control group peers by approximately 5.5 scale score points (effect size = 0.40, $p = 0.001$). With regard to high school coursetaking, AR students who had access to online Algebra I in grade 8 were about twice (1.96 times) as likely to participate in an advanced high school course sequence than their peers in schools where Algebra I is typically not offered to grade 8 students ($p = 0.007$).

Secondary Questions and Results

The results of the secondary impact analyses suggest that there were no significant negative (or positive) effects on AR students' general mathematics achievement at the end of grade 8. Having access to Algebra I in grade 8 through an online course (instead of taking the general grade 8 mathematics course) did not reduce students' scores on a general mathematics assessment. This finding has policy relevance, because middle schools participate in state accountability assessments that test a range of general mathematics areas that may include but are not limited to algebraic concepts.

Secondary impact analyses of outcomes for N-AR students suggest that the implementation of online Algebra I in the study schools did not have any discernible effects on students who were not considered eligible for the course. Specifically, there were no treatment effects on N-AR students' algebra or general mathematics achievement at the end of grade 8. Moreover, the probability of a N-AR student enrolling in a grade 9 mathematics course at or above Algebra I—an indicator of participation in an intermediate course sequence in high school—was not significantly different for students from treatment and control schools. Taken together, the analyses of N-AR students suggest that although schools' grade 8 mathematics programs were altered with the adoption of the online Algebra I course, students who remained in the general grade 8 mathematics class did not learn less algebra or have a lower chance of enrolling in Algebra I as grade 9 students than they would have had their school not adopted the online course for their AR students.

Conclusions Based on Primary and Secondary Findings

This combination of findings is consistent with the framework presented in Chapter 1 for evaluating the effectiveness of using an online course to broaden students' access to Algebra I. A

successful intervention in this context was defined as one that yielded positive impacts on either end-of-grade 8 algebra achievement or subsequent high school coursetaking for AR students, with no significant negative side effects on AR students' general mathematics scores or on any achievement or coursetaking outcomes for N-AR students. The results showed that AR students with access to online Algebra I in grade 8 outperformed their counterparts in control schools on an end-of-year algebra assessment and were more likely to follow an advanced course sequence in high school. There were no side effects of the course on AR students' end-of-year general mathematics achievement or on any of the N-AR students' measured outcomes. Thus, the results suggest that offering an online course to AR students in grade 8 is an effective way to broaden access to the specific course, and later, to more challenging mathematics course opportunities, for students in schools that do not typically offer Algebra I to eighth graders.

The study was designed to provide information to educators who are looking for ways to offer a key gateway course (Algebra I) to their grade 8 students who are ready for it, but for various reasons cannot typically offer full access to the course in a standard or traditional way. The goal for the intervention was to not only have an impact on AR students' short-term algebra knowledge, but to also influence a sequence of mathematics opportunities and outcomes over time. The hypothesis associated with the primary questions for this study was that offering an online Algebra I course would benefit student outcomes in contrast to the mathematics instruction they would have received in absence of the online course. It may seem obvious that students with access to an online Algebra I course in grade 8 should learn more algebra and take more advanced courses earlier in high school than those that do not. For multiple reasons, however, the results observed in the primary and secondary analyses were not necessarily obvious and addressed gaps in the research base.

First, before this study, there was no prior rigorous evidence that an online version of a formal Algebra I course could be offered to grade 8 students by schools that do not typically offer the course, in terms of technology and content support. Second, though the logistical implementation of the course went as planned, just under half (43%) of the AR students who enrolled in the course fully completed it, meaning that many of the AR students in the treatment group were not exposed to the entire course. At the same time, AR students in control schools were exposed to a substantial amount of algebraic content in the context of their general mathematics classes, and one out of five AR control students actually did take a formal Algebra I course. Despite these circumstances, this study still demonstrated that the intervention as implemented is more effective in promoting students' success in mathematics than existing practices in these schools.

Exploratory Analyses and Results

Two sets of exploratory analyses examined AR students' high school coursetaking more closely. First, the effect of access to online Algebra I in grade 8 on the likelihood of initial enrollment in an advanced course in grade 9 was examined using planned course enrollments. Like the analyses of coursetaking after a full year of high school, this exploratory analysis showed that AR students in treatment schools were more than three times as likely to enroll in an advanced course (that is, a course above Algebra I) than AR students in control schools (predicted probabilities = 0.54 and 0.16 for AR students in treatment and control schools, respectively; $p = 0.005$).

A second exploratory analysis tested the effect of online Algebra I in grade 8 on the likelihood that AR students doubled up on mathematics courses in grade 9 or 10. According to the data collected, at least some high-achieving students without access to Algebra I in grade 8 get themselves on track for an advanced course sequence by doubling up on their mathematics courses. Twenty-one percent of the AR sample (a total of 96 students) took more than one full-year mathematics course in grade 9, planned to do so in grade 10, or both. The results indicate that access to online Algebra I in grade 8 significantly decreased the likelihood that students doubled up. Specifically, the results indicate that students in control schools (predicted probability = 0.23) were more than twice (2.3 times) as likely to double up in mathematics courses in grade 9 or grade 10 than AR students in treatment schools (predicted probability = 0.10; $p = 0.033$). If the students who planned to double up did successfully complete Algebra II, by the end of grade 10 (beyond the duration of the study), they could feasibly “catch up” to their peers categorized as advanced coursetakers for the purpose of the study’s main analysis at the beginning of grade 11. From an instructional and developmental perspective, however, doubling up on high school mathematics courses may be a poorer option than sequential engagement in the course content. A longer study is needed to determine whether beginning this course sequence in grade 8 impacts the quality of students’ mathematics learning throughout the course sequence and whether the various pathways do in fact continue (or converge) throughout high school and beyond.

In sum, the exploratory analysis findings supplement the main analyses and suggest that in addition to affecting *whether* students pursue an advanced course sequence, the intervention had an impact on *how* students enter an advanced course pathway—that is, access to Algebra I through an online course in grade 8 can reduce the need to double up and thus may allow high-achieving students who would otherwise double up to take other high school courses and focus on one mathematics content area at a time

Limitations of the Study and Future Research Directions

This study was conducted with a sample of schools in Maine and Vermont that met the eligibility criteria for participation and agreed to take part in a random assignment study. Many of these schools were small (48% had grade 8 enrollments of less than 17 students), and 90% were in rural areas. Analyses of ECLS-K data (U.S. Department of Education 2009a) indicated that a significant proportion of schools do not offer Algebra I to grade 8 students (approximately 16% nationally); moreover, the proportion of schools in rural areas with limited access to Algebra I is higher than in urban and suburban areas. Still, it is not clear whether the study schools represent small rural schools located in other parts of the region or country or the extent to which the results observed in these schools generalize to other schools interested in using online courses to expand access to Algebra I to grade 8 students.

Although the consent rates and response rates were high (greater than 95% in the AR sample and greater than 85% in the N-AR sample), they were not 100%. Multiple imputation was used to adjust for any bias nonresponse might introduce, but it is not impossible that bias was nonetheless present.

One potential source of bias in the study was the difference by condition observed on the study-administered pretest, on which AR students from treatment schools both scored higher and spent

more time than did AR students from control schools. However, the availability and use of mathematics achievement scores from the state assessments taken the year prior to the study mitigated the potential threat that these differences might otherwise cause the study findings.

The online course chosen, Class.com's Algebra I course, is similar in content and focus to the offerings of other providers. However, it is not clear that similar results would have been observed had another course provider been chosen. Moreover, the results observed in this study cannot necessarily be generalized to more recently developed online courses.

For all these reasons, replication of this study is necessary to gain a better understanding of the potential impacts of using an online course to expand access to Algebra I to grade 8 students. In particular, future studies should examine longer-term effects of access to online Algebra I in grade 8—through high school, college, and even beyond. This study included a one-year follow-up to track students from grade 8 into high school. A longer study is needed to assess whether access to online Algebra I in grade 8 continues to have an impact on participation in advanced mathematics coursetaking through the end of high school.

As the use of online courses continues to increase in U.S. schools, future research should continue to study their effects on student coursetaking patterns and achievement in key content areas. Further investigation of the effectiveness of online courses should contrast the offering of them with various relevant business-as-usual situations. These include school settings where students' lack of access to specific courses (where the control group does not take the course) as well as school settings where particular courses are oversubscribed or taught by under-qualified or uncertified teachers (where the control group would take a standard face-to-face version of the online course).

Schools around the country, particularly those in rural areas, are in search of innovative ways to expand their course offerings. To address this need, this study focused on the use of an online course to provide access to Algebra I in schools that do not typically offer the course in grade 8. It did not compare the effects of taking online Algebra I versus a standard face-to-face version of the course in grade 8, and the results should not be interpreted to indicate that offering online Algebra I is better than (or as good as) offering a face-to-face Algebra I course to eighth graders. In addition, given that the study compared the offering of an online Algebra I course to a lack of (or limited) access to Algebra I in grade 8, it is not possible to isolate the portion of the observed effects that is due to the fact that the course was online. As noted in the earlier description of the intervention under test, the content of the course (Algebra I) cannot be untangled from the mode of instruction (online). Thus it is possible that broadening access to any type of formal Algebra I course to AR grade 8 students would yield similar effects.

This study is the first of its kind to rigorously evaluate the impact of offering an online version of Algebra I in schools that otherwise do not typically offer the course, even though they have students who are ready to take it. For educators and students facing similar challenges, the results of this study may be particularly informative and promising.

APPENDIX A: STUDY DESIGN, STUDY SAMPLES, AND STATISTICAL PRECISION

This appendix provides details about the design and implementation of the study, including information on the school and student samples and estimates of the study’s statistical precision based on the data used in the analysis.

School and Student Samples

The CONSORT flow chart (figure A-1) identifies the number of students on whom pretest and posttest data were collected and the number of students included in the analytic samples for the analysis of algebra posttest scores, coursetaking outcomes, and general mathematics scores.

Two types of students were defined as out of scope of the sample. The parents of 68 students (5 algebra ready and 63 non–algebra ready) withdrew them from data collection. Forty-six N–AR students were withdrawn from the study by their schools because of their special education status. These students were deemed “not testable” and out of scope of the sample.

Among students who were in scope of the sample, there were three main reasons for a missing score on the pretest or the algebra and general mathematics posttests:

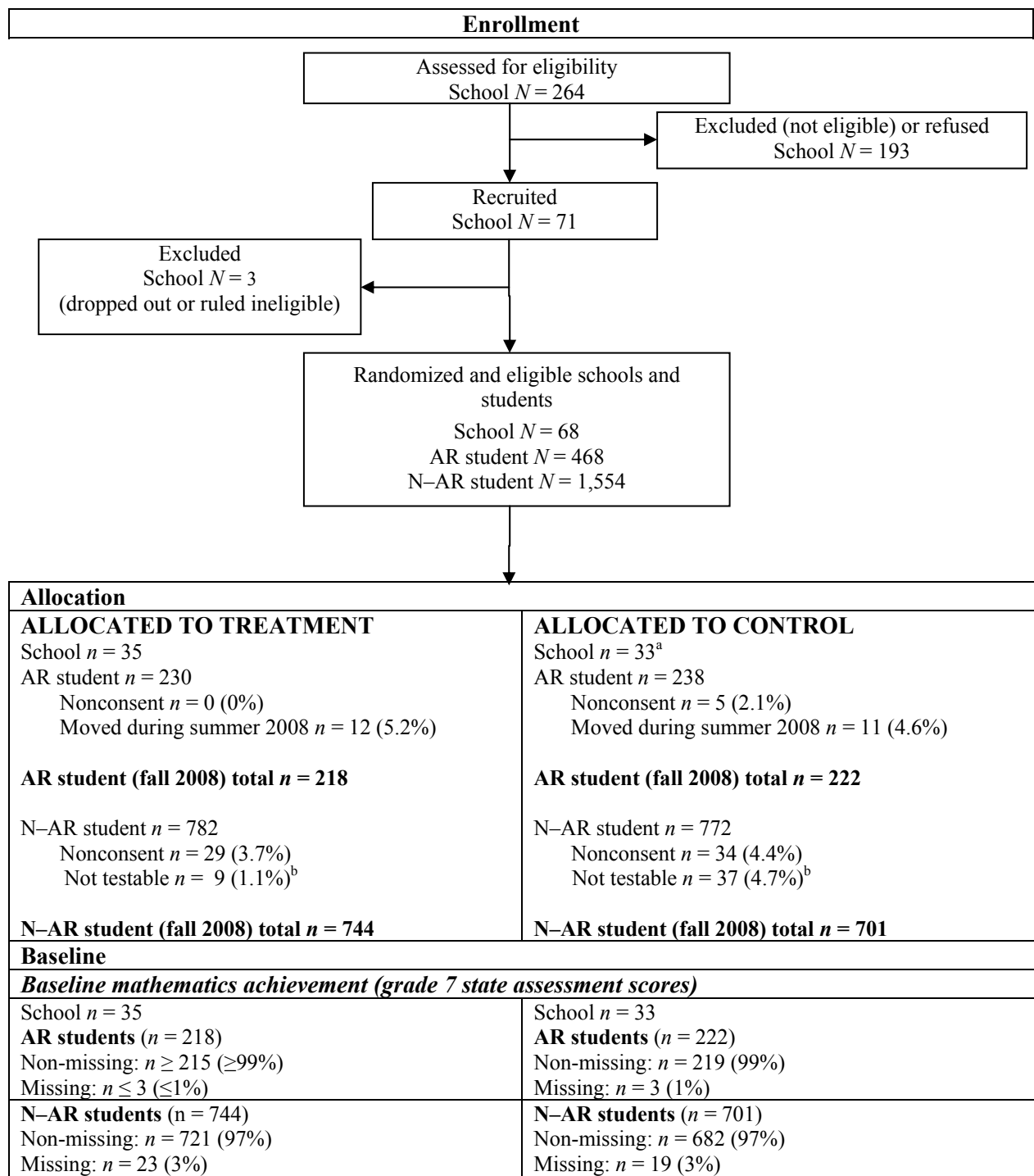
- Persistent absence on testing days
- A score based on low testing time, defined as less than five minutes, which was considered invalid by the test developer
- A move out of the participating school (and not into another participating school) during the 2008/09 school year.⁵³

Information on planned grade 9 courses was missing primarily because of lack of availability at the time of collection (for example, the course registration was not yet set at the time of collection). Information on students who had moved out of a participating school was also generally not available.

Information on actual high school courses taken was missing because schools did not provide the data when requested or individual student data were not available from the high schools because the student had moved. Data were provided by 63 of 66 high schools (95%) within the time frame (June–July 2010).

⁵³ Students who moved out of a participating school and into another participating school were retained in the sample and remained in their original school for the purpose of clustering and analysis.

Figure A-1. CONSORT Flow Chart and Sample Tracking



Pretest—general mathematics	
School $n = 35$ AR students ($n = 218$) Not tested: $n \leq 3$ Response rate = $\geq 99\%$ ($\geq 215/218$) Missing rate = $\leq 1\%$ ($\leq 3/218$)	School $n = 33$ AR students ($n = 222$) Tested: $n = 218$ Not tested: $n = 4$ Absent $n = 4$ Response rate = 98% ($218/222$) Missing rate = 2% ($4/222$)
N–AR students ($n = 744$) Tested: $n = 724$ (of these, 10 cut because students spent less than five minutes on test) Not tested: $n = 20 \rightarrow$ Absent $n = 20$ Response rate = 97% ($724/744$) Missing rate = 4% ($30/744$) ^c	N–AR students ($n = 701$) Tested: $n = 676$ (of these, 6 cut because students spent less than five minutes on test) Not tested: $n = 25 \rightarrow$ Absent $n = 25$ Response rate = 96% ($676/701$) Missing rate = 4% ($31/701$) ^c
Follow-up	
Posttest—algebra	
School $n = 35$ AR students ($n = 218$) Not tested: $n \leq 3$ Response rate = $\geq 99\%$ ($\geq 215/218$) Missing rate = $\leq 1\%$ ($\leq 3/218$)	School $n = 33$ AR students ($n = 222$) Not tested: $n \leq 3$ Response rate = $\geq 99\%$ ($\geq 219/222$) Missing rate = 2% ($4/222$)
N–AR students ($n = 744$) Tested: $n = 703$ (of these, 73 cut because student spent less than five minutes on the test) Not tested: $n = 41$ Absent $n = 13$ Moved $n = 28$ Response rate = 94% ($703/744$) Missing rate = 15% ($114/744$) ^c	N–AR students ($n = 701$) Tested: $n = 656$ (of these, 45 cut because student spent less than five minutes on the test) Not tested: $n = 45$ Absent $n = 7$ Moved $n = 38$ Response rate = 94% ($656/701$) Missing rate = 13% ($90/701$) ^c
Posttest—general mathematics	
School $n = 35$ AR students ($n = 218$) Not tested: $n \leq 3$ Response rate = $\geq 99\%$ ($\geq 215/218$) Missing rate = $\leq 1\%$ ($\leq 3/218$)	School $n = 33$ AR students ($n = 222$) Tested: $n = 219$ Not tested: $n = 3$ Absent $n = 0$ Moved $n = 3$ Response rate = 99% ($219/222$) Missing rate = 1% ($3/222$)
N–AR students ($n = 744$) Tested: $n = 703$ (of these, 13 cut because student spent less than five minutes on the test) Not tested: $n = 41$ Absent $n = 13$ Moved $n = 28$ Response rate = 95% ($703/744$) Missing rate = 7% ($54/744$) ^c	N–AR students ($n = 701$) Tested: $n = 656$ (of these, 4 cut because student spent less than five minutes on the test) Not tested: $n = 45$ Absent $n = 7$ Moved $n = 38$ Response rate = 94% ($656/701$) Missing rate = 7% ($49/701$) ^c

<i>Planned grade 9 mathematics courses</i>	
School $n = 35$ AR students ($n = 218$) Not collected: $n = 3$ Response rate = 99% (215/218) Missing rate = 1% (3/218)	School $n = 33$ AR students ($n = 222$) Collected: $n = 211$ Not collected: $n = 11$ (not known at time of collection or student moved) Response rate = 95% (211/222) Missing rate = 5% (11/222)
N-AR students ($n = 744$) Collected: $n = 697$ Not collected: $n = 47$ Not available $n = 19$ Moved $n = 28$ Response rate = 94% (697/744) Missing rate = 6% (47/744)	N-AR students ($n = 701$) Collected: $n = 652$ Not collected: $n = 49$ Not available $n = 11$ Moved $n = 38$ Response rate = 93% (652/701) Missing rate = 7% (49/701)
<i>High school coursetaking (actual grade 9 courses and grades, planned grade 10 courses)</i>	
AR students ($n = 218$) Collected: $n = 211$ Not collected: $n = 7$ (not provided or student moved) Response rate = 97% (211/218) Missing rate = 3% (7/218)	AR students ($n = 222$) Collected: $n = 216$ Not collected: $n = 6$ (nonconsent, not provided, or student moved) Response rate = 97% (216/222) Missing rate = 3% (6/222)
Analysis	
<i>Algebra posttest</i>	
AR analysis sample School $n = 35$ Student $n = 218$ Fewer than 4 posttest scores imputed	AR analysis sample School $n = 33$ Student $n = 222$ 4 posttest scores imputed
N-AR analysis sample School $n = 35$ Student $n = 744$ 114 posttest scores imputed	N-AR analysis sample School $n = 29^a$ Student $n = 701$ 90 posttest scores imputed
<i>General mathematics posttest</i>	
AR analysis sample School $n = 35$ Student $n = 218$ Fewer than 4 posttest scores imputed	AR analysis sample School $n = 33$ Student $n = 222$ Fewer than 4 posttest scores imputed
N-AR analysis sample School $n = 35$ Student $n = 744$ 54 posttest scores imputed	N-AR analysis sample School $n = 29^a$ Student $n = 701$ 49 posttest scores imputed

<i>Planned grade 9 mathematics courses</i>	
AR analysis sample School $n = 35$ Student $n = 218$ Fewer than 4 planned grade 9 course indicators imputed	AR analysis sample School $n = 33$ Student $n = 222$ 11 planned grade 9 course indicators imputed
N–AR analysis sample School $n = 35$ Student $n = 744$ 47 planned grade 9 course indicators imputed	N–AR analysis sample School = 29 ^a Student $n = 701$ 49 planned grade 9 course indicators imputed
<i>Actual high school coursetaking</i>	
AR analysis sample School $n = 35$ Student $n = 218$ 7 high school coursetaking indicators imputed	AR analysis sample School $n = 33$ Student $n = 222$ 6 high school coursetaking indicators imputed
N–AR analysis sample: na	N–AR analysis sample: na

na is not applicable. AR is algebra ready. N–AR is not algebra ready.

Note: To maintain the confidentiality of participants, measures with fewer than three missing data cases were suppressed for presentation purposes.

a. Four control schools did not have any N–AR students (all grade 8 students were classified as algebra ready).

b. Students who were not testable were designated so by their schools (because of special education status and the schools' determination that appropriate accommodations on the study-administered assessments could not be feasibly provided).

c. The response rate and missing rate calculations do *not* include students who were deemed not testable by their schools or whose parents withdrew them from the study (nonconsent). Missing rates (but not response rates) count missing students whose scores were cut because they spent less than five minutes on the test. Therefore, missing rates and response rates do not always sum to 100%.

Student Samples

In June 2008, before random assignment, schools were required to identify the students they considered ready for algebra. A common criterion for defining “algebra ready” was not established, and schools varied in their approach. It was not clear at the time of random assignment whether schools would systematically identify their high-achieving students as algebra ready or use other criteria.

The first approach to determining whether the AR sample was higher achieving than the N–AR students and whether the two groups differed in other ways was to test for differences in their characteristics. Across treatment and control conditions, researchers used a two-level model that accounts for the clustering of students within schools and includes the blocking factors used for randomization. The results indicate the following:

- A smaller percentage of AR students than N–AR students received free or reduced-price lunch.
- A smaller percentage of AR students than N–AR students received special education services.
- AR students' scores on both the prior year's state mathematics assessment and the study-administered pretest were significantly higher than those of N–AR students.

AR and N–AR students in the study schools did not significantly differ on other demographic factors (table A-1).

Table A-1. Baseline Characteristics of AR and N–AR Students in Study Schools

Characteristic	AR		N–AR		<i>p</i> -value
	Number	Percent	Number	Percent	
Eligible for free or reduced-price lunch	139	32	670	46	< 0.001
Receives special education services	15	3	252	17	< 0.001
Has limited English proficiency	15	3	43	3	0.843 ^a
Female	214	49	717	50	0.476
Racial/ethnic minority	29	7	75	5	0.369
	Number	Mean	Number	Mean	
Mean grade 7 score on state mathematics assessment (standardized) ^b	437	0.95 (0.69)	1,403	–0.24 (0.86)	< 0.001
Mean fall 2008 pretest score (Promise Assessment) ^c	435	349.87 (23.27)	1,384	312.60 (27.23)	< 0.001

AR is algebra ready. N–AR is not algebra ready.

Note: Sample includes 68 schools (35 treatment, 33 control). Values represent unadjusted means. Differences in school characteristics by sample were tested using a model that accounted for the clustered data structure and blocking used for randomization. Figures in parentheses are standard deviations.

a. Model did not estimate when controlling for five state by size dummy blocking variables. Reported *p*-value represents a model that controls for state and two dummy indicators for medium and large schools rather than their interactions.

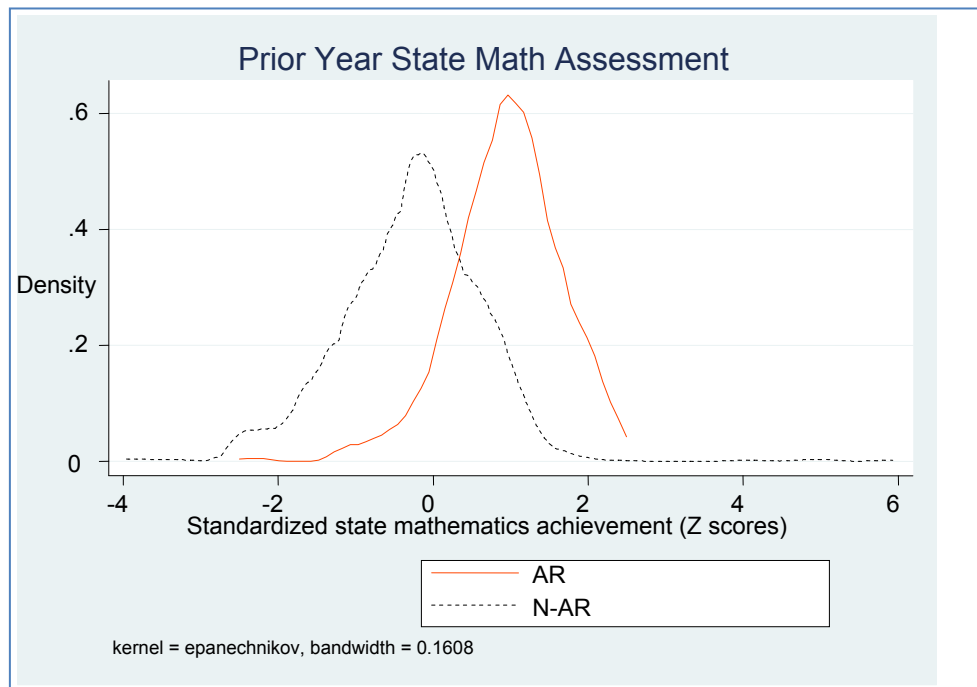
b. State assessment scores were standardized by using the mean and the standard deviation of the test scores within each state, including only schools participating in the study.

c. The Promise Assessment test was administered in the first month of the school year and is therefore not a pure pretreatment measure.

Source: Maine state department of education and Vermont supervisory unions, study records.

To further examine the extent to which AR and N–AR students represent different populations, researchers examined density plots of the sample distributions on the prior year’s state mathematics assessment (figure A-2) and the pretest (figure A-3). Although there is clear overlap in the distributions, there is evidence to suggest that schools did identify their higher-achieving students as algebra ready.

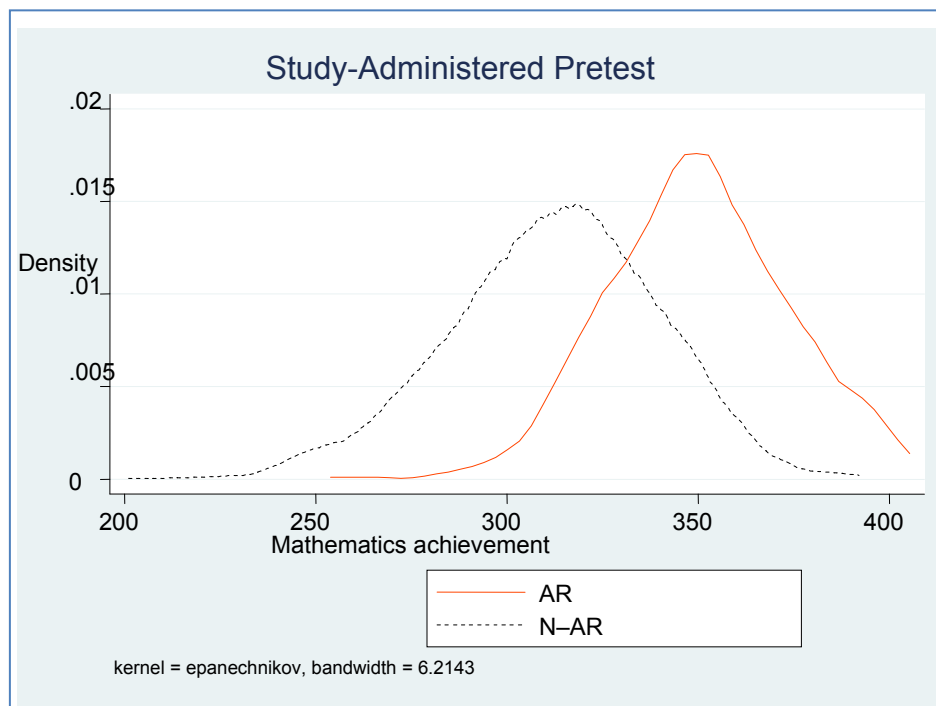
Figure A-2. AR and N-AR Ready Distributions on Prior Year State Mathematics Assessment



AR is algebra ready. N-AR is not algebra ready.

Source: Maine state department of education and Vermont supervisory unions.

Figure A-3. AR and N-AR Distributions on Pretest



AR is algebra ready. N-AR is not algebra ready.

Source: Study-administered pretest.

Estimates of Statistical Precision Based on Data Used in Analyses

Minimum detectable effect sizes were calculated based on Bloom (2005, equation 8). As the intervention was designed to have a direct effect on students' mathematics knowledge and skills and a minimum detectable effect size of 0.25 is considered necessary for an intervention effect to have "educational significance" (Bloom et al. 2008), the study team established a target effect size for the analysis of impact of the intervention on AR students of 0.25:

$$MDES = M_{J-K} \sqrt{\frac{\rho(1-R_c^2)}{P(1-P)J} + \frac{(1-\rho)(1-R_I^2)}{P(1-P)nJ}}$$

where

- P = proportion of sample schools allocated to the online algebra treatment (0.5).
- J = total number of schools in study sample.
- K = number of school-level covariates used.
- n = number of students per school at posttest and follow-up.
- ρ = school-level intraclass correlation.
- R_c^2 = proportion of the variance between schools that is reduced by the covariate (school-level explanatory power).
- R_I^2 = proportion of student-level variance component explained by student-level pretests.
- M = multiplier that translates the standard error into an estimate of minimum detectable effect size. It is equal to the t critical value for α , the significance level of the intended statistical test, plus the t critical value for β , the likelihood of detecting significant effects given a true effect of a particular size (that is, the power of the test).

Assumed Statistical Power for Impact Analyses with AR Students

Calculations of the minimum detectable effect size for analysis of algebra achievement at the end of grade 8 are based on the following assumptions:

Statistical power: 80%.

Statistical significance level: Alpha of 0.025 for a two-tailed test, adjusted for multiple comparisons (two outcomes).

Number of schools (actual): 68.

Number of students per school (actual): Each school served an average of 32 grade 8 students, 6.54 (20%) of whom were identified as algebra ready. Power calculations were conducted assuming 88% response rates (that is, six AR students per school at posttest).

Proportion of students in treatment condition: 50%.

Covariate adjustment:

School level: Researchers assumed that two-thirds of the school-level variance in the achievement outcome would be explained by the baseline mathematics scores.⁵⁴ They assumed that half of the school-level variance in the coursetaking outcome would be explained by the pretest. Two additional school-level covariates were the indicators for the two variables by which schools were blocked for random assignment: state and size.

Student level: Researchers assumed that pretest scores and additional student-level covariates, including gender, eligibility for free or reduced-price lunch, and special education status, would explain 50% of the variance in posttest scores (that is, $R^2 = 0.50$).

Intraclass correlation: Researchers assumed an intraclass correlation value of 0.12. This value is based on Hedges and Hedberg's 2007 empirical analysis of intraclass correlations using a nationally representative dataset from the Longitudinal Study of American Youth (LSAY). In that analysis, the unadjusted (unconditional) intraclass correlation for grade 8 mathematics for rural schools in the Northeast region of the country was 0.12 (Hedges, personal communication, October 15, 2007).

Blocking: Calculations of minimum detectable effect size assume blocking by two stratification variables: state (Maine, Vermont) and school size based on the total number of grade 8 students served (small: fewer than 17; medium: 17–70; large: more than 70). Power analyses assumed that random assignment of schools was conducted separately within each block, resulting in an equal number of intervention and control schools within each block.

Based on these assumptions, researchers calculated a minimum detectable effect size of 0.25 for the algebra achievement outcome. Using a similar set of assumptions but a lower correlation between pretest and outcome, they calculated a minimum detectable effect size of 0.27 for the coursetaking outcome.

Assumed Statistical Power for Impact Analyses for N–AR Students

Calculations of the minimum detectable effect size for analysis of outcomes for the full N–AR sample were based on the same assumptions as for the full AR student sample, except for the number of students per school and the significance level. For secondary analyses involving the N–AR sample, researchers assumed an alpha of 0.05 for a two-tailed test of statistical significance, with no adjustment for multiple comparisons; an average of 22.9 N–AR students per school; and power calculations that assume 88% response rates at follow-up (20 N–AR students per school). Based on these assumptions, a minimum detectable effect size of 0.19 was calculated for the analysis of impacts on mathematics achievement (algebra and general mathematics) at the end of grade 8 for N–AR students and 0.22 for the analysis of impacts on coursetaking by N–AR student.

⁵⁴ The assumption that 66% of the variance in posttest scores would be explained by pretest scores is based on the correlation of school-level average scores on Maine's mathematics assessment in grades 7 and 8, which was 0.81.

APPENDIX B: MEASURES

This appendix provides detail on the instruments and measurement strategies used in this study. These measures include measures of implementation derived from classroom observations, proctor logs, a teacher survey, and classroom materials.

This appendix also provides detail on the outcome measures (Promise Assessment and coding protocol for planned high school courses). For each type of measure, it describes the development of instruments, data collection procedures, and analytic procedures, including scale construction.

Implementation Measures

Classroom Observations

Study team members visited all treatment schools to observe how the online Algebra I course was being implemented. The following protocol items were completed in all 35 schools.

Figure B-1. Protocol for Observing Implementation of Online Algebra I Class

General Information
Observer name:
Date and time of class period:
School name:
Proctor name:
Proctor position at school:
Where do students access the online algebra course? (Check one) ☐ Library ☐ Computer lab ☐ Classroom with regular 8th grade math class ☐ Classroom separate from regular 8th grade math class ☐ Other (please specify):
Did the proctor or other staff member have other responsibilities or do other work during the visit? Yes No

Proctor Logs

The proctors who supervised the students in the online course completed a weekly web-based log to record the amount of time they engaged in different types of activities as part of their proctor role. The first set of questions asked proctors to report how much time, in minutes, they spent that week on the following activities:

- Answering students' questions about algebra
- Answering students' questions about nonalgebra mathematics

- Providing technical/computer support
- Proctoring quizzes or tests
- Communicating with the online teacher
- Contacting technical support from Class.com
- Contacting technical support from their school
- Transferring student grades from the online course to their school's grade book or grading system
- Handling scheduling or other administrative issues
- Addressing student behavioral problems.

The second set of questions asked proctors to report the number of communications they had during the week with the online teacher, technical support at Class.com, and technical support at their school.

Teacher Survey

Researchers administered the teacher survey online in spring 2009 to all grade 8 mathematics teachers in study schools and to the online Algebra I teachers. The survey served two main purposes. First, it provided data on characteristics of the teachers (for example, degree earned, years of teaching experience). Second, it provided data on the organization and delivery of grade 8 mathematics instruction in treatment and control schools, as well as in the online Algebra I classes.

The data supplemented the analyses of class size and ability grouping. The teacher survey included an item that asked teachers to list the number of students enrolled in each section of grade 8 mathematics they taught. This item was used to calculate the average number of students per section at each school, which is reported in chapter 3 when comparing the class sizes in treatment and control schools.

The teacher survey also included two items that asked teachers to describe the extent to which they provided different types of instruction based on the ability levels of students in their classrooms. One item asked teachers to describe the extent to which they differentiated their instructional practices in general. The other asked teachers to describe the extent to which they provided accelerated learning opportunities (such as Algebra I) for higher-ability students. These items were used to describe teachers' instructional practices in chapter 3.

Classroom Materials

To estimate content coverage in the general grade 8 mathematics classes in study schools, the study team collected instructional materials, including pacing guides and course syllabi, textbook information/tables of contents, classroom assignments, and exams. While visiting schools during the spring 2009 posttest administration period, trained field staff used a protocol to collect relevant classroom materials from grade 8 classroom teachers. The protocol guided data

collectors to ask all teachers to name the textbooks they used and to submit a table of contents, annotated with the topics covered, so that the study team could determine how much of the curriculum/textbook each teacher completed. In addition, the protocol guided data collectors to ask teachers to submit more detailed information if available, including example assignments or exams, pacing guides, or any other materials that described the content taught in their course.

The study team collected course materials from 60 schools. The materials were coded on the basis of the type of material collected, the percentage of class time spent on algebra topics, and the textbooks used. Seven control schools offered a separate Algebra I course for certain grade 8 students. Researchers computed a weighted average (described below) to measure the algebraic content focus at these schools.

The study team received tables of contents from 50 schools (27 control schools, 23 treatment schools). Teachers who returned tables of contents that were not annotated were assumed to have completed all units listed. Researchers also collected 17 pacing guides and 12 annotated syllabi. Notes on pacing guides helped researchers determine the amount of time spent on each mathematics topic. When the team received a syllabus that was not annotated, it assumed that all topics had been completed.

A code of 1–4 was given to each set of materials submitted (1 = 25% of time spent on algebra, 2 = 50% of time spent on algebra, 3 = 75% of time spent on algebra, 4 = 100% of time spent on algebra). The coding was guided by the identification of algebraic terms that were consistent with the 11 items from the section on the teacher survey addressing algebra content. The coding process was conducted by two team members with experience reviewing mathematics curricula, including one senior mathematics expert. The junior team member first coded all 61 sets of materials. The senior mathematics expert then coded a random selection of 10 sets of classroom materials. The only area of disagreement involved one set of *Connected Math* materials, for which the coders differed by 1 (2 versus 3). Because *Connected Math* was the most common curriculum, the senior mathematics expert recoded these schools. For control schools that included both an Algebra I course and a general mathematics course, researchers computed a weighted school average based on the number of students assigned to each course within each school. For example, the weighted average for a control school in which 8 students took a separate Algebra I course coded 4 and 10 took a general grade 8 mathematics course coded 2 would be $[(8*4)+(10*2)]/18$ or 2.89. With rounding, this school would be coded 3.

The most common mathematics textbook/curriculum used in both treatment and control schools was Pearson-Prentice Hall *Connected Mathematics* (table B-1). Many of the units in this program focus on algebra content, covering such topics as patterns and sequences, linear equations and inequalities, algebraic expressions, and quadratic equations. However, the curriculum is not organized like that in a typical Algebra I textbook. Instead of following the chapter and single-day lesson structure of a typical Algebra I textbook, *Connected Mathematics* is organized into four- to five-week units that address a common mathematical theme or idea. Each unit focuses on the overarching mathematical idea through several multiday investigations that are often grounded in a real-world or practical context. Thus, although *Connected Mathematics* has a sharp focus on algebraic concepts, the concepts are presented in a format different from that of a typical Algebra I textbook. Eighteen schools (9 control, 9 treatment) used this program. McDougal Littell *Math Themes* was the second most popular text, with 13

schools (8 control, 5 treatment). The most common Algebra I materials were Holt *Algebra I* and Prentice Hall *Algebra I*. Other common grade 8 mathematics texts included Glencoe *Mathematics Course 3*, Glencoe *MathScape*, Saxon *Course 3 (Algebra ½)* and Forseman-Wesley *Math*.

Table B-1. Mathematics Textbooks Used in Study Schools

Textbook	Website for more information	Number of schools
Pearson/Prentice Hall <i>Connected Mathematics</i>	http://www.phschool.com/cmp2/	18
McDougal Littell <i>Math</i>	http://holtmcdougal.hmhco.com/hm/math.htm	13
Glencoe <i>Mathematics Course 3</i>	http://www.glencoe.com/sec/math/msmath/mac04/course3/	8
Glencoe <i>MathScape</i>	http://www.glencoe.com/sec/math/mathscape/index.php/	4
Saxon <i>Course 3 (Algebra ½)</i>	http://saxonpublishers.hmhco.com/en/sxnm_middle.htm	4
Prentice Hall <i>Algebra I</i>	http://www.phschool.com/atschool/ph_algebra/program_page.html	4
Holt <i>Algebra I</i>	http://go.hrw.com/gopages/ma/alg1_07.html	4
Foresman-Wesley <i>Math</i>	http://www.pearsonschool.com/index.cfm?locator=PSZu6e&PMDBSUBCATEGORYID=25741&PMDBSITEID=2781&PMDBSUBSOLUTIONID=&PMDBSOLUTIONID=6724&PMDBSUBJECTAREAID=&PMDBCATEGORYID=806&PMDbProgramId=5052&elementType=programComponents	4

Source: Classroom materials.

Study-Administered Pretest and Outcome Measures

The pretest, general mathematics posttest, and algebra posttest used in this study were computer-adaptive tests called the Promise Assessments, developed by SEG Assessment and Internet Testing Systems. The Promise Assessment has been administered to more than 200,000 students since 2007 to assess and diagnose mathematical strengths and weaknesses.

The Promise Assessment battery is composed of two assessments: the pre-algebra mathematics assessment, a grade 3–8 assessment of mathematical skills, and an assessment of skills associated with elementary algebra (Algebra I). The pre-algebra mathematics assessment measures the range of mathematics content covered in grades 3–8, including number and number sense, computation and estimation, measurement, geometry, probability and statistics, patterns, functions and algebra. The Algebra I assessment measures content related to equations and inequalities, algebraic manipulation and graphing systems of equations, polynomials, quadratic equations, and functions and expressions. The two assessments may be used alone or together, depending on the assessment and the instructional needs of the user.

The Promise Assessments are delivered online. The instrument determines which items to administer on the basis of each student's response to previous items. In this way, the test assesses students' skills in the shortest amount of time.

For the fall implementation, the Promise General Mathematics Assessment was delivered as a 30-item computer-adaptive test. For the spring implementation, the Promise General Mathematics Assessment was delivered as a 20-item computer-adaptive test and the Promise Algebra Assessment was delivered as a 20-item computer-adaptive test.

Development and Psychometric Properties of the Promise Assessment

Approximately 2,500 test items were written to measure prealgebra skills in grades 3–8 and algebra. The test items were written to match the Virginia Standards of Learning (http://www.doe.virginia.gov/testing/sol/standards_docs/index.shtml). Those standards, developed to reflect the range of skills expected of students in grades 3–8 and in Algebra I, were based largely on other nationally developed mathematics standards. Approximately 15–20 test items align to each standard. Approximately 30% of the items included graphic stimuli, such as a geometric figure, a table, or a graph. Information on item development, field testing, item analysis, and calibration is available upon request from the test developer.

Scaling and Scoring. One of the benefits of the linking and calibration design is the ability to place all items and individuals on a single underlying scale reflecting algebra readiness for the General Mathematics Assessment and a single underlying scale reflecting algebra skill for the Algebra Assessment. For each scale, the scores were initially calibrated on a scale ranging from –3 to +3 (with a mean of 0 and standard deviation of 1).

The standard scale values were then linearly transformed. The General Mathematics Assessment was linearly transformed to a scale of 200–400, with a mean of 300 and a standard deviation of 33. The Algebra Assessment was linearly transformed to a scale of 400–500, with a mean of 450 and a standard deviation of 17. As linear transformations, these scales may be interpreted consistently with the underlying –3 to +3 standard scale.

Reliability. Reliabilities of the Promise Assessment General Mathematics and Algebra tests are reported as the Rasch person reliability estimates for the norming population on which the tests are scaled. The reliabilities reported by the test developer were 0.87 for the General Mathematics Assessment (standard 30-item test), 0.83 for the General Mathematics Assessment (as a 20-item test), and 0.80 for the Algebra Assessment (as a 20-item test). The study team calculated the reliability of the tests as used in this study on the sample of all grade 8 students in study schools who took each assessment (AR and N–AR combined). The estimated reliabilities of the scores were 0.83 for the general mathematics pretest, 0.77 for the general mathematics posttest, and 0.71 for the algebra posttest.

Standard Error of Measurement. The overall standard error of measurement was estimated as the standard deviation multiplied by the square root of the test reliability subtracted from 1 (standard deviation $\times$ $\text{SQRT}(1 - r_{xx})$). The Rasch-based reliability estimate was used in calculating the standard errors of measurement, which were as follows:

- 30-item General Mathematics Assessment: 12.71 scale points (200–400 scale)
- 20-item General Mathematics Assessment: 15.56 scale points (200–400 scale)
- 20-item Algebra Assessment: 8.93 scale points (400–500 scale).

Validity. The developers of the Promise Assessment General Mathematics test claim that the scores measure a student’s level of prealgebra mathematics proficiency in relation to mathematics standards in grades 3–8. The Promise Assessment Algebra test purportedly measures a student’s level of algebra proficiency in relation to mathematics standards defining the typical Algebra I course. Validation is an ongoing process of collecting evidence in support

of the test and test scores. Several steps have been taken to establish the validity of the Promise Assessment.

- The test items were developed by mathematics subject matter experts.
- The test items were developed specifically to measure each of the standards for which the program was developed.
- The test items were reviewed multiple times for content accuracy, alignment, and freedom from potential bias.
- The test items were reviewed by mathematics educators on two separate occasions (online and face to face).
- The test items were field-tested with more than 20,000 students.
- The test items were calibrated and found to fit with the expected mathematical model (Rasch one-parameter model).
- The test items were reviewed, and any item that failed to meet established psychometric criteria was eliminated.
- The dimensionality of the test was reviewed and confirmed to be a unidimensional construct.
- Students performed as expected on the field test, with the mean test results for each grade falling in an expected, ordered pattern (that is, grade 8 students performed better than grade 7 students, who performed better than grade 6 students, and so forth).
- A simulation study of the computer-assisted test algorithm in which 100 tests were “taken” by simulated examinees at a range of ability levels found that the computer-assisted test produced scores as expected (table B-2).

Table B-2. Results of Simulation Study of Computer-Assisted Test

Simulated ability level	Average observed ability level across 100 trials
-2	-1.95
-1	-1.01
0	-0.01
1	0.96
2	2.04

Source: Internet Testing Systems and SEG Assessment.

Sample Items

The sample items shown in this section denote the level of item difficulty at a particular scaled score. A student of ability level X is said to have a 50% probability of correctly answering an item at the same difficulty level. For example, approximately 50% of all students earning a scaled score of 200 would correctly answer the sample item shown for a scaled score of 200. The sample items provided are not official Promise Assessment items.

General Mathematics Assessment. The general mathematics assessment was scored on a scale of 200-400. Fifty percent of students with a score of 200 (a low score, associated with an ability level of -3.0) on the general mathematics posttest would correctly answer the following item:

Sample Item 1: Scaled Score = 200 or $\vartheta = -3.0$

Which statement is true?

- A. $256 > 321$
- B. $517 < 541$
- C. $300 = 301$
- D. $472 < 468$

Correct response: B

Fifty percent of students with a score of 300 (an average score, associated with an ability level of 0.0) would correctly answer the following item, which is more difficult:

Sample Item 2: Scaled Score = 300 or $\vartheta = 0.0$

Which method can be used to solve the number sentence below?

$$6 + x = 13$$

- A. Multiply each side by 6.
- B. Divide each side by 6.
- C. Add 6 to each side.
- D. Subtract 6 from each side.

Correct Response: D

A student with a score of 400 (a high score, associated with an ability level of 3.0) would correctly answer the following item, which is more difficult:

Sample Item 3: Scaled Score = 400 or $\vartheta = 3.0$

A 20-foot ladder is leaning against a house. The foot of the ladder was placed 6 feet from the side of the house. About how high up the side of the house does the ladder reach?

- A. 14 feet
- B. 19 feet
- C. 20 feet
- D. 21 feet

Correct Response: B

Algebra Assessment. The algebra mathematics assessment was scored on a scale of 400–500. Fifty percent of students with a score of 400 (a low score, associated with an ability level of -3.0) on the algebra posttest would correctly answer the following item:

Sample Item 1: Scaled Score = 400 or $\vartheta = -3.0$

$-5(2x + 3) = 20$ can be simplified to $-10x - 15 = 20$ by using which property?

- A. transitive property of equality
- B. reflexive property of equality
- C. associative property of multiplication
- D. distributive property of multiplication

Correct Response: D

Fifty percent of students with a score of 450 (an average score, associated with an ability level of 0.0), would correctly answer the following item:

Sample Item 2: Scaled Score = 450 or $\vartheta = 0.0$

Factor the expression $4x^2 + 20x + 25$.

- A. $(2x + 5)(2x - 5)$
- B. $(2x + 5)^2$
- C. $(2x - 5)^2$
- D. $(2x + 25)(2x + 1)$

Correct Response: B

Students with a score of 490 (a high score, associated with an ability level of 3.0), would correctly answer the following item:

Sample Item 3: Scaled Score = 490 or $\theta = 2.4$)

How many solutions does this system of equations have?

$$y = -\frac{3}{8}x^2 - 5$$
$$y + \frac{3}{4}x - 7 = 0$$

- A. no solutions
- B. infinite solutions
- C. only one solution
- D. only two solutions

Correct Response: D

Administration of Promise Assessment

Collection of Pretest Data. In early fall 2008, the Promise Assessment was administered to all grade 8 students in schools participating in the study. The majority of students participating in the study (59%) completed the pretest before the end of September 2008. All pretesting was completed by mid-October 2008. In all schools, the pretest was administered by staff at the school, including grade 8 mathematics teachers, technology specialists, other teachers, and principals.

Before the administration of the pretest, the study team collected full rosters of all grade 8 students, including their names, their state identification (ID) numbers, and the names of each student's mathematics class and teacher. The study team used these rosters to create materials for the pretest that included electronic templates to upload into the online assessment system; attendance rosters for study liaisons to log the completion date of the pretest for each student and note any accommodations made; and personalized, individual log-in sheets showing each student's name and secure, study-specific ID.

Each student logged in to the system and was routed to the pretest for the study. The test followed the procedures defined by Internet Testing Systems, the company that delivers the Promise Assessment, beginning with a brief tutorial on how to use the features of the computerized test. These features include selecting and changing answer choices, moving between items, using tools such as protractors, and ending the test. After students completed the tutorial, the first test item was presented. The difficulty of the test was adjusted to match each student's performance, so each student saw different items. Item difficulty was based on whether a student gave correct responses to items up to that point. As a student answered correctly, the questions became more difficult; incorrect answers were followed by easier items.

Variation in Time Spent on Test. Because the Promise Assessment is administered online through a web-based testing system, precise information on the amount of time spent by each

student on the test was available to the study team. These data indicated that there was school-level variation in the administration of the assessment. In particular, the study team identified a difference by condition in the amount of time, on average, spent on the pretest by both AR and N-AR students. Specifically, students in treatment schools spent more time on the test than students in control schools (table B-3).

Table B-3. Average Time (in Minutes) Spent on Promise Assessment Pretest

Student sample	Treatment schools (standard deviation)	Control schools (standard deviation)	Difference	p-value
AR	33.20 (13.78)	28.02 (9.49)	5.18	0.039
N-AR	25.05 (9.87)	22.99 (7.99)	2.06	0.038

AR is algebra ready. N-AR is not algebra ready.

Note: Sample includes 68 schools (35 treatment, 33 control); 436 AR students (217 treatment, 219 control); and 1,400 N-AR students (724 treatment, 676 control). Four control schools had no N-AR students. Data were missing for 4 AR students and 45 N-AR students. Reported means, standard deviations, and statistics tests represent observed data (before imputation).

Statistical tests comparing treatment and control students were performed on an imputed dataset; no changes in statistical significance emerged. The means and standard deviations reported are observed, not model adjusted; the *p*-values are based on a model estimating the effect of treatment status on testing time, controlling for school-level state by size blocking variables.

Source: Promise Assessment Pretest results.

On average, AR students in treatment schools spent five minutes longer on the pretest than AR students in control schools. On average, N-AR students in treatment schools spent two minutes longer on the pretest than their counterparts in control schools. The differences were statistically significantly for both groups.

The difference in testing time in treatment and control schools indicates a “late pretest problem” for this assessment of baseline mathematics achievement. It is possible that the reason for the testing time difference is that schools that were randomly assigned to the treatment condition were more aware of being in the study than schools assigned to control and that treatment schools, teachers, and students therefore took the pretest more seriously.

All scores based on very low testing times (defined as less than five minutes) were excluded from analysis. There were no such scores among AR students on the pretest; among the N-AR sample, 16 scores were cut for this reason (10 in treatment schools and 6 in control schools).

Collection of Posttest Data. The study team implemented a similar procedure for the posttest assessment, except that trained members of the study team visited each school to administer the test. The purpose of this change was to standardize administration across schools for the measurement of the key achievement outcomes at the end of grade 8. The study team arranged a site visit with each school to administer the posttest. The same instructions were given to students in all schools. In all cases, students first received the 20-item general mathematics posttest and then received the 20-item algebra posttest.

There was not a significant difference in testing time on the algebra portion of the posttest for AR students. However, a sensitivity analysis was conducted to ensure that testing time on this primary outcome (algebra posttest scores) did not account for the observed treatment effect (see appendix E, model E.7). As with the pretest, there was a significant difference by condition in the amount of time spent on the general mathematics posttest by AR students (table B-4): on

average, AR students in treatment schools spent nearly four minutes longer than AR students in control schools. There were no significant differences in testing time by condition on either posttest for N–AR students.

Table B-4. Average Time (in Minutes) Spent on Promise Assessment Posttests

Posttest	Student sample	Treatment schools	Control schools	Difference	<i>p</i> -value
Algebra Posttest	AR	17.69 (6.85)	15.87 (6.00)	1.82	0.139
	N–AR	12.76 (6.46)	12.22 (5.36)	0.54	0.159 ^a
General Math	AR	21.85 (8.60)	18.31 (6.43)	3.54	0.002
	N–AR	17.62 (7.90)	16.70 (6.65)	0.92	0.161

AR is algebra ready. N–AR is not algebra ready.

Note: Sample includes 68 schools (35 treatment, 33 control); 436 AR students (217 treatment, 219 control); and 1,400 N–AR students (724 treatment, 676 control). Four control schools had no N–AR students. Data were missing for 4 AR students and 45 N–AR students. Reported means, standard deviations and statistics tests represent observed data (before imputation). Figures in parentheses are standard deviations.

a. *p*-value became significant (.047) in the imputed dataset.

Source: Promise Assessment Pretest results.

Scores based on testing times of less than five minutes were excluded from analysis. There were no such scores among AR students on the general mathematics posttest; there were fewer than four such scores among AR students on the algebra posttest. Among the N–AR sample, 17 scores were cut because of low testing time on the general mathematics posttest (13 treatment, 4 control), and 118 were cut on the algebra posttest (73 treatment, 45 control). The large number of students who completed the test in less than five minutes may indicate that the test was difficult for N–AR students who did not take an Algebra I course in grade 8.

High School Mathematics Courses

The coding of the transcript data for impact analyses was based on methods used by the National Center for Education Statistics for the National Assessment of Educational Progress and Education Longitudinal Study transcript studies (U.S. Department of Education 2007a; 2007b). Transcript coding protocols guided the extraction of course identifiers. Mathematics education experts coded the course titles using the Classification of Secondary School Courses, which is based on information available in school catalogs and other information sources (U.S. Department of Education 2007b). The study team used the procedures described below to collect and code high school courses, including planned grade 9 courses (at the end of grade 8 for all students) and grade 9 and 10 course information (at the end of grade 9 for AR students).

Planned Grade 9 Courses

While visiting schools during the spring 2009 posttest administration period, trained field staff collected information on planned grade 9 courses from participating schools. The study team trained the field staff in April 2009, covering all aspects of spring data collection, including posttest and survey administration, collection of classroom materials, and collection of the planned grade 9 course information for all students in the school.

In many schools, students had not yet registered for their high school courses. In these cases, the information was collected at a later date by following up with the middle school study liaison by email or telephone. The school information was defined as the source for planned grade 9 courses. Continued verification of the course information occurred through summer 2009.

Each planned grade 9 course was coded in a two-phase process. Phase one involved assignment of codes, based on a scheme based on the Classification of Secondary School Courses Hierarchical Mathematics Course Listing:

- 1 = course below Algebra I (Pre-Algebra, Algebra I A)
- 2 = Algebra I (or the second half of an Algebra I course [for example, Algebra I B])
- 3 = Algebra I Honors (includes Advanced, Accelerated)
- 4 = course above Algebra I (for example, Algebra II, Geometry, Calculus).

Throughout the coding process, the study team took steps to ensure that the data provided by the schools were reviewed carefully and coded consistently. The study team accomplished this by double coding, checking for interrater reliability, and using the study's mathematics content experts to resolve discrepancies. In addition, it examined grade 9 course information from the high schools (for example, course catalogs, course descriptions on the web) and contacted relevant personnel from middle or high schools in a few cases.

All courses with the standard titles Pre-Algebra, Algebra I, Geometry, and Algebra II were coded by two junior members of the study team. Courses with different titles (for example, Algebra IA, Integrated Mathematics II) were coded by two senior content experts from the study team. If the course titles were ambiguous for the content expert, the junior team members conducted web searches and found syllabi and course catalogs to provide clarification. One of the senior mathematics experts first coded all the courses with ambiguous titles. Any course titles that were unclear were flagged and then double-coded by the second mathematics content expert. There were 66 such cases. The two experts independently agreed on 62 of the 66 cases and came to resolution on the remaining cases via discussion.

After Phase 1 coding was complete, planned courses were collapsed into three categories:

- 1 = course below Algebra I in the Classification of Secondary School Courses sequence
- 2 = Algebra I (includes Honors and Accelerated Algebra courses)
- 3 = courses above Algebra I in the Classification of Secondary School Courses sequence.

AR students' planned coursetaking was categorized as advanced or not advanced. The analysis tested the impact of online Algebra I on the likelihood of enrolling in an advanced grade 9 course. N-AR students' planned coursetaking was categorized as being intermediate or not intermediate, where an intermediate sequence begins with Algebra I in grade 9. This lower bar for the N-AR student sample was considered to be appropriate given that they were not identified as ready for algebra as rising grade 8 students.

To analyze the likelihood of AR students' initially enrolling in an advanced course in grade 9, the study team collapsed the Phase 2 codes into a binary variable:

- 0 = course with a Phase 2 code of 1 or 2 (Algebra I or lower)
- 1 = course with a Phase 2 code of 3 (above Algebra I).

The analysis of this outcome is ancillary to the main high school coursetaking outcome based on follow-up data for the AR sample. It is reported as an exploratory analysis in chapter 5.

To analyze N–AR students’ likelihood of following an intermediate course sequence in grade 9 (as indicated by enrollment in an Algebra I course rather than a lower-level course), the study team collapsed the Phase 2 codes into a second binary variable:

- 0 = course with a Phase 2 code of 1 (course lower than Algebra I)
- 1 = course with a Phase 2 code of 2 or 3 (course at or above Algebra I).

The analysis of this outcome addresses one of the secondary research questions for the N–AR sample and is reported in chapter 4. (No additional follow-up information on N–AR students’ coursetaking was collected.)

Actual Grade 9 Courses

During the spring 2009 data collection (when students were at the end of grade 8), researchers collected information on which high school each student planned to attend the following fall. In fall 2009 (when students began grade 9), the study team began preparing for high school course data collection by assigning one study liaison to each of the high schools AR students planned to attend. To the high school principals or mathematics department chairs, the liaisons described the goals of the study, identified key contacts for future data collection, discussed how the spring 2009 data would be collected, and determined whether the AR students who planned to attend each high school were actually enrolled. If students had transferred from the planned high school to another high school, researchers asked for the name of the new high school and contacted the new high school. For AR students who never attended the planned high school, researchers followed up with the middle schools to find out where the students ultimately enrolled. A total of 66 high schools received AR students in the 2009/10 school year.

The liaisons also collected course catalogs and any other information the high schools could provide about the types of mathematics courses they offered and how they fit into the school’s mathematics course sequence or sequences. The study team reviewed these materials to ensure that it had sufficient information to code the courses. The liaisons followed up with any schools for which additional data were needed. From the course information for each high school, researchers built a database that included the names of the courses, the credit structure, grading scales, and descriptions of each course (for example, prerequisites, key mathematics content covered). The database was completed before data collection began in May 2010—the earliest date by which any of the high schools had given final course grades.

Liaisons worked with high schools to establish the most efficient and reliable way to collect the course data. The primary way in which data were entered was through an online system that included all the information from the database previously described. The liaison entered the information in one of two ways. The first way was by calling a representative from each high

school and entering the data as the representative provided the information over the telephone. The liaison then asked the high school representative to view the information that had been entered online and then to confirm the accuracy of the information by clicking a confirmation button. The second way was for the high school representative to enter the information directly into the system or complete an electronic template provided by the study team that included all the coursetaking variables (name of course, grade, and so forth).

As with the planned grade 9 course data, the Classification of Secondary School Courses hierarchy was used to code the grade 9 and 10 course data. The grade 9 course titles and course grades and the planned grade 10 course titles were used to create the following composite coursetaking outcome, representing participation or nonparticipation in an advanced course sequence. The composite binary code was based on the following components:

- **Grade 9 mathematics course types.** The codes for grade 9 course types are the same as those for planned grade 9 courses: 1 = course above Algebra I, 0 = course at or below Algebra I.
- **Grade 9 mathematics grades.** Grades earned by AR students in their grade 9 mathematics course were converted into a binary measure of “success” versus “not success”: 1 = grade equivalent of A, B, or C (success), 0 = grade equivalent of D or F (not success). If students took more than one mathematics course in grade 9, the grade associated with the more advanced course taken was used.
- **Grade 10 mathematics course types.** The type of mathematics course in which each AR student enrolled for grade 10 was coded on the basis of the Classification of Secondary School Courses into the following categories: 1 = Algebra II or other course above Geometry in the typical course sequence, 0 = Geometry or other course below Algebra II in the typical course sequence.

Composite Measure of Advanced Coursetaking

The composite measure is a simple binary measure that represents whether students participated in an advanced mathematics course sequence in high school. Researchers assigned a 1 to all AR students who were assigned a 1 for all three of the component coursetaking measures (that is, the composite coursetaking code = 1 if the grade 9 course type = 1 and the grade 9 course grade = 1 and the grade 10 course type = 1; otherwise, the composite coursetaking code = 0). The composite measure is a binary variable that signifies participation or nonparticipation in an advanced sequence of mathematics courses with a grade of at least C.

Most high schools followed one of two sequences: Algebra I → Geometry → Algebra II or Algebra I → Algebra II → Geometry, using these course titles. In these cases, course progressions were easy to classify as advanced or not advanced. Some course titles and sequences were less clear. For example, some schools used programs that integrated Algebra I, Geometry, and Algebra II content and offered accelerated versions of these courses. These cases required a more careful review of the course descriptions in the high school course catalogs. Where necessary, study team members called high school mathematics educators to clarify and confirm their interpretations of their course sequences.

Researchers began the coding process by creating a file that included the relevant course information for each student. (This file did not include any information that could be used to identify the treatment status of any students in the dataset.) Almost all the data were double-coded by two study team members with expertise coding high school courses, including one senior mathematics content expert. The same two coders led the coding of the planned high school courses in 2009, making them familiar with the content and process. The only data that were not double coded were cases in which the junior coder was unclear. These cases—approximately 10% of the sample—were then reviewed and discussed by the junior coder and the senior content expert in light of course catalog descriptions and additional information from high schools where necessary.

APPENDIX C: INTERVENTION FEATURES

This appendix describes the features of the online Algebra I course offered as the intervention in this study.

Online Algebra I Course Content

Algebra IA

Algebra IA is designed to be equivalent to the first semester of a traditional middle/high school Algebra I course. This course covers, algebraic concepts, including integers, linear equations, linear inequalities, absolute value, polynomials, and factoring.

Course Content

- Unit 1: Introduction to Algebra
 - Symbols in Algebra
 - Properties and Sentences
 - Real Numbers and the Number Line
- Unit 2: Introduction to Equations
 - Combined Operations
 - Introduction to Function and Equations
 - Solving Equations Analytically
- Unit 3: Solving Equations
 - Equations and Problem-Solving
 - Percentages
- Unit 4: Inequalities and Absolute Value
 - Inequalities
 - Absolute Value
- Unit 5: Polynomials
 - Monomials
 - Combining
 - Factoring

Course Objectives

- Develop the fundamental algebraic skills of factoring polynomials, simplifying and evaluating expressions, and solving equations.
- Apply algebraic problem-solving strategies to real-world situations.
- Use graphing technology to interpret and solve equations and inequalities.
- Communicate mathematical ideas, analyze mathematics situations, explain procedures for correct computation, and describe results using graphical, numerical, or algebraic representations.
- Use the Internet to obtain useful information.
- Develop a sense of class membership, using newsgroups and Moodle learning management system to communicate with teacher and classmates.

The following list includes all scorable activities and assessments available as part of Algebra IA. (As with a traditional face-to-face course online teachers had the option of “turning off” particular activities such as within-unit exercises.).

- 13 quizzes: At the end of each lesson in the course, students take a computer-graded quiz covering topics covered in the lesson. Students have one chance to take each quiz. Quiz results are automatically stored in the online environment grade report.
- 5 unit exams: At the end of each unit in the course, students take a computer-scored unit exam covering all lessons in the unit. Students have one chance to take the exam. Unit exam results are automatically stored in the online environment grade report.
- 1 final exam: At the end of the course, students take a two-part computer-graded final exam that covers topics from the entire course. Students have one chance to take the exam. Exam results are automatically stored in the online environment grade report.
- 5 assignments: Each unit includes one assignment, which is completed online. Each assignment was created as part of the online quiz system. Teachers and proctors, but not other students, are able to see student responses. The assignments include open-ended or guiding questions that are not computer graded and not automatically included in the online environment grade report.
- 5 discussions: Each unit includes one discussion assignment. The discussions were created as a forum in the online environment; they allow student responses to other students’ work and can include multiple threads. Teachers, proctors, and all students in the section can see the entire discussion. The discussions include open-ended questions that are not computer graded and not automatically included in the online environment grade report.

Algebra IB

Algebra IB is designed to be equivalent to the second semester of a traditional middle/high school Algebra I course aligned to the Maine and Vermont content standards. In this course, students continue their progression through algebraic concepts, expanding their knowledge of

functions and relations, solving systems of equations and inequalities, simplifying rational and radical expressions, and solving quadratic equations. A unit on probability and statistics is also included to help students analyze data and make predictions about real-world situations using a variety of visual representations.

Course Content

- Unit 1: Linear Equations
 - Functions and Relations
 - Graphs and Linear Equations
 - Other Forms of Linear Equations
 - Variation
- Unit 2: Systems of Equations and Inequalities
 - Solutions by Graphing
 - Solving Systems of Equations
 - Problem Solving
- Unit 3: Rational Expressions and Radicals
 - Rational and Irrational Numbers
- Unit 4: Quadratic Equations
 - Solving Quadratic Equations
 - Quadratic Equations and Problem Solving
- Unit 5: Statistical Analysis
 - Measure of Variability
 - Probability
- Unit 6: Variation, Rational Expressions, and Radicals
 - More Operations on Rational Expressions
 - Operations with Radicals
- Supplemental Topic: Additional Statistical Analysis
 - Organizing Data and Variability

Course Objectives

- Add, subtract, multiply, and divide rational expressions.
- Solve and graph linear functions.
- Solve systems of equations and inequalities.
- Perform operations with radicals.

- Solve radical equations.
- Solve quadratic equations.
- Analyze and interpret data represented in various real-world situations.
- Apply algebraic problem-solving strategies to real-world situations.
- Use graphing technology to solve, interpret, analyze, and compare linear functions and relations, inequalities, absolute value graphs, and quadratics.
- Communicate mathematically by expressing ideas, analyzing situations, explaining procedures for correct computation, and describing results numerically and graphically.
- Use the Internet to obtain useful information.
- Develop a sense of class membership, using newsgroups, discussions, and email to communicate with teacher and classmates.

The following list includes all possible scorable activities and assessments available as part of Algebra IB.

- 17 quizzes: At the end of each lesson in the course, students take a computer-graded quiz covering topics in that lesson. Students have one chance to take each quiz. Quiz results are automatically stored in the online environment grade report.
- 6 unit exams: At the end of each unit in the course, students take a computer-graded unit exam covering all the lessons in that unit. Students have one chance to take the exam. Unit exam results are automatically stored in the online environment grade report.
- 1 final exam: At the end of the course, students take a two-part computer-graded final exam covering topics from the entire course. Students have one chance to take the exam. Exam results are automatically stored in the online environment grade report.
- 6 assignments: Five units include at least one assignment; Unit 3 includes two assignments. Each assignment was created as part of the online quiz system and is done online. Teachers and proctors, but not other students, are able to see student responses. The assignments include open-ended or guiding questions that are not computer graded and are not automatically included in the online environment grade report.
- 6 discussions: Four units include one discussion, Unit 3 includes two discussions, and Units 5 and 6 do not include any discussions. The discussions were created as a forum in the online environment; they allow student responses to other students' work and can include multiple threads. Teachers, proctors, and all students in the section can see the entire discussion. The discussions include open-ended questions that are not computer graded and not automatically included in the online environment grade report.

Alignment of the Class.com Online Algebra I Course with Two Typical Algebra I Textbooks

Table C-1 presents the percentage of lessons in Class.com Algebra IA and IB, the *Algebra: University of Chicago School Mathematics Project* textbook (McConnell 2002), and the *Glencoe Algebra I* textbook (Holliday et al. 2005) devoted to 11 typical Algebra I topics. These two

textbooks were chosen for alignment purposes because they are widely used in standard Algebra I courses in the region and across the country.

Table C-1. Percentage of Lesson Content Devoted to Various Algebra I Topics by Class.com and Two Standard Textbooks

Topic	Class.com Algebra IA and IB	University of Chicago School Mathematics Program Algebra	Glencoe Algebra
Patterns and sequences (arithmetic, geometric)	2.8	4.0	3.3
Simplifying and evaluating algebraic expressions	19.4	17.2	14.3
Functions (function notation, identifying functions)	5.6	9.1	2.2
Solving linear equations	11.1	7.1	14.3
Solving linear inequalities	2.8	3.0	2.2
Graphing linear equations (intercept and point-slope form of linear equations)	8.3	10.1	11.0
Graphing linear inequalities	2.8	2.0	1.1
Solving systems of linear equations and inequalities	11.1	8.1	5.5
Solving quadratic equations (factoring, quadratic formula)	11.1	8.1	11.0
Graphing quadratic equations	2.8	4.0	3.3
Solving and graphing other types of equations (polynomial, square root, absolute value)	2.8	5.0	4.4
Other	19.4	22.2	27.5

Note: All 36 lessons in the Class.com Algebra IA and IB course were included in this analysis.

Source: Study team analysis based on review of topics and lessons in Class.com course and the UCSMP and Glencoe Algebra I textbooks.

APPENDIX D: ESTIMATION METHODS AND HYPOTHESIS TESTING

This appendix describes the estimation methods used in and the hypothesis testing conducted for the study.

Confirmatory Impact Analyses

Primary Impact Analyses

The analytic strategy was to compare students from schools randomly assigned to receive the intervention with students from schools that do not receive the intervention. Because treatment groups are determined at the school level, the primary unit of analysis is the school. The data for this study are hierarchical (students are nested within schools); therefore, units at the same level are not statistically independent. Ignoring the nested structure of the data yields misleadingly small standard errors for treatment effect estimates (see Seltzer 2004; Raudenbush and Bryk 2002; Snijders and Bosker 1999). Given the hierarchical data structure in a cluster randomized setting, this study used hierarchical linear modeling to estimate the treatment effect on the outcomes of interest. Analyses using hierarchical linear modeling allow the effects of student- and school-level factors to be modeled and adjustments made for the nonindependence of observations within clusters. In all analyses, researchers estimated two-level models, where students were the Level 1 unit and schools the Level 2 unit.

To handle missing data in the AR sample, researchers used multiple imputation with chained equations. All analyses of the AR sample were conducted with 10 multiply imputed datasets; the estimates presented in this appendix are averages based on the 10 datasets. For more information on the multiple imputation of missing data, see appendix F.

Chapter 4 presented summarized results including model-based group means (for achievement outcomes) and predicted probabilities (for coursetaking outcomes) along with *p*-values for the effect of condition. The results presented here are the coefficients and standard errors for all of the variables in each model, including student- and school-level covariates. The full-model coursetaking results additionally include corresponding odds ratios and 95 percent confidence intervals for each predictor.

Primary Research Question 1. To address Research Question 1, researchers calculated the intent-to-treat estimate of the effect of treatment status, using algebra posttest scores (Promise Assessment algebra score) at the end of grade 8 as the outcome.

The following two-level model was specified:

$$\begin{aligned} Algebra_{ij} = & \beta_{0j} + \beta_{1j}(StateMath_{ij} - StateMath..) + \beta_{2j}(SpEd_{ij} - SpEd..) + \beta_{3j}(FRL_{ij} - FRL..) \\ & + \beta_{4j}(Female_{ij} - Female..) + \epsilon_{ij} \end{aligned} \quad (D.1a)$$

$$\beta_{0j} = \gamma_{00} + \gamma_{01} TRT_j + \gamma_{02} (MaineMED_j - MaineMED.) + \gamma_{03} (MaineLG_j - MaineLG.) + \gamma_{04} (VermontSM_j - VermontSM.) + \gamma_{05} (VermontMED_j - VermontMED.) + \gamma_{06} (VermontLG_j - VermontLG.) + u_{0j} \quad (D.1b)$$

$$\beta_{1j} = \gamma_{10} \quad (D.1c)$$

$$\beta_{2j} = \gamma_{20} \quad (D.1d)$$

$$\beta_{3j} = \gamma_{30} \quad (D.1e)$$

$$\beta_{4j} = \gamma_{40} \quad (D.1f)$$

where $Algebra_{ij}$ is the algebra achievement score for student i in school j at the end of grade 8 (that is, the posttest) and $StateMath_{ij}$ is the prior state mathematics score (standardized) for student i in school j . In the Level 1 model presented in equation D.1a, all covariates are centered on the grand mean, so that β_{0j} represents the adjusted mean for school j .

The intent-to-treat estimate is specified in the first equation of the Level 2 model (equation D.1b). TRT_j is an indicator variable that takes a value of 1 for treatment schools and 0 for control schools; γ_{00} represents the average algebra achievement score for control schools; and γ_{01} captures the difference in algebra achievement score between treatment schools and control schools (that is, the impact of the treatment when all other covariates are centered at the grand mean). The estimate γ_{01} is reported as a standardized effect size, based on the pooled standard deviation for the treatment and control groups on the algebra posttest. A pooled standard deviation that accounts for both within and between imputation variance (Rubin 1987; Shafter & Graham 2002) was used to calculate an effect size across 10 imputed datasets.

The model includes the following student-level covariates (centered on the grand mean):

- Prior state mathematics assessment scores (*StateMath*), standardized within state using sample data only
- Eligibility for free or reduced-price lunch (*FRL*) eligibility status (dummy variable coded 0 = not eligible, 1 = eligible)
- Eligibility for special education services (*SpEd*) (dummy variable coded 0 = not eligible, 1 = eligible)
- Gender (dummy variable coded 0 = girls, 1 = boys).

At Level 2, five dummy variables that capture state by size interactions were included, with small schools in Maine serving as the reference block:

- Medium-size schools in Maine versus all other schools (*MaineMED*) (dummy variable coded 1 for medium-size schools in Maine, 0 for all other schools).
- Large-size schools in Maine versus all other schools (*MaineLG*) (dummy variable coded 1 for large-size schools in Maine, 0 for all other schools).
- Small-size schools in Vermont versus all other schools (*VermontSM*) (dummy variable coded 1 for small-size schools in Vermont, 0 for all other schools).

- Medium-size schools in Vermont versus all other schools (*VermontMED*) (dummy variable coded 1 for medium-size schools in Vermont, 0 for all other schools).
- Large-size schools in Vermont versus all other schools (*VermontLG*) (dummy variable coded 1 for large-size schools in Vermont, 0 for all other schools).

These student- and school-level variables were used as covariates in all analytic models for this study to improve the precision of the estimates of impact (table D-1). Variables were selected that were expected to be highly correlated with the outcome measure.

Table D-1. Results of Main Impact Model Predicting AR Students' Algebra Posttest Scores

Variable	Coefficient	Standard error	p-value	Effect size
Intercept	441.64	1.11	< 0.001	
<i>School covariate</i>				
Condition	5.53	1.57	0.001	0.40
Medium-size school in Maine	1.48	1.96	0.454	
Large-size school in Maine	2.55	2.73	0.354	
Small-size school in Vermont	4.73	3.11	0.133	
Medium-size school in Vermont	2.49	3.50	0.479	
Large-size school in Vermont	3.14	3.06	0.311	
<i>Student covariate</i>				
Female	0.09	1.13	0.939	
Receives special education services	-11.18	3.54	0.002	
Eligible for free or reduced-price lunch	1.98	1.30	0.129	
State mathematics score (standardized) ^a	9.87	1.18	< 0.001	
Chi-squared (degrees of freedom)				
	Variance		p-value	
Residual	127.59			
Level 2 (school)	10.67	87.71 (61)	0.014	
Total variance	138.26			

Note: Sample includes 68 schools (35 treatment, 33 control) and 440 AR students (218 treatment, 222 control). Estimates were averaged across 10 multiply imputed datasets. The effect size was calculated using a pooled standard deviation of the outcome for AR students in treatment and control schools that incorporates both within and between imputation variance (13.78).

a. Because Maine and Vermont use different tests, it was necessary to translate scores into a common metric. The scores were standardized by using the mean and standard deviation of the test scores within each state, including only schools participating in the study.

Source: Algebra scores on study-administered Promise Assessment posttest.

Researchers conducted six sensitivity analyses that test the robustness of the observed estimates from the benchmark impact model. These analyses test models with different methods of accounting for students' baseline mathematics achievement, a model with no covariates, a model based on observed (nonimputed) data only, and a model that tests an alternative nesting structure (with students in treatment schools clustered within online teachers). The results of these sensitivity analyses of the algebra outcome are reported in appendix E (models E.1–E.6).

Primary Research Question 2. To address Research Question 2, the study team calculated the intent-to-treat estimate of the effect of treatment status, using participation in an advanced mathematics course sequence as the outcome.

The following two-level hierarchical generalized linear model was used to examine the difference between the probability of participating in an advanced mathematics course sequence

in high school by AR students in treatment schools and control schools. Given a Bernoulli sampling model and a logit link function, the study team specified the following Level 1 model:

$$\eta_{ij} = \beta_{0j} + \beta_{1j}(\text{StateMath}_{ij} - \text{StateMath}_{..}) + \beta_{2j}(\text{SpEd}_{ij} - \text{SpEd}_{..}) + \beta_{3j}(\text{FRL}_{ij} - \text{FRL}_{..}) + \beta_{4j}(\text{Female}_{ij} - \text{Female}_{..}) \quad (\text{D.2a})$$

where $\eta_{ij} = \log(\varphi_{ij} / 1 - \varphi_{ij})$ (that is, the log of the odds of participating in an advanced mathematics course sequence) and φ_{ij} is the probability of advanced coursetaking for student i in school j . If the probability of advanced coursetaking φ_{ij} is 0.5, the odds of advanced coursetaking $\eta_{ij} = \log(\varphi_{ij} / 1 - \varphi_{ij}) = 0.5 / .5 = 1.0$, and the log-odds (or logit) is $\log(1.0) = 0$. If the probability of advanced coursetaking is less than 0.5, the odds are lower than 1.0, and the logit is negative.

StateMath_{ij} is the (standardized) prior state mathematics score for student i in school j . In the Level 1 model presented in equation D.2a, all covariates are centered on the grand mean. The Level 1 model estimates the difference in log odds of participating in an advanced mathematics course sequence in high school by AR students from treatment schools and control schools, holding prior state mathematics assessment scores constant.

The Level 2 models (including the same school-level variables as the previously specified model for algebra achievement at the end of grade 8) are as follows:

$$\begin{aligned} \beta_{0j} = & \gamma_{00} + \gamma_{01} \text{TRT}_j + \gamma_{02} (\text{MaineMED}_j - \text{MaineMED}_{..}) + \gamma_{03} (\text{MaineLG}_j - \\ & \text{MaineLG}_{..}) + \gamma_{04} (\text{VermontSM}_j - \text{VermontSM}_{..}) + \gamma_{05} (\text{VermontMED}_j - \\ & \text{VermontMED}_{..}) + \gamma_{06} (\text{VermontLG}_j - \text{VermontLG}_{..}) + u_{0j}. \end{aligned} \quad (\text{D.2b})$$

$$\beta_{1j} = \gamma_{10}. \quad (\text{D.2c})$$

$$\beta_{2j} = \gamma_{20}. \quad (\text{D.2d})$$

$$\beta_{3j} = \gamma_{30}. \quad (\text{D.2e})$$

$$\beta_{4j} = \gamma_{40}. \quad (\text{D.2f})$$

The key parameter of interest is γ_{01} , the overall difference in log odds of participating in an advanced mathematics course sequence in high school between AR students in treatment schools and control schools. Unit-specific estimates are presented for all categorical models.

The descriptive results for advanced coursetaking indicate that among AR students, 53% from treatment middle schools and 30% from control middle schools were participating in an advanced course sequence in high school (table D-2).

Table D-2. Percentage of AR Students Taking Advanced Mathematics Course Sequence in High School

High school mathematics course sequence	Students from treatment schools	Students from control schools	All AR students
Advanced	53.3	29.5	41.3
Not advanced	46.7	70.5	58.7

AR is algebra ready.

Note: Sample includes 68 schools (35 treatment, 33 control) and 440 AR students (218 treatment, 222 control). Percentages are calculated across 10 multiply imputed datasets. Coursetaking patterns were coded as representing successful completion of a course above Algebra I in grade 9 and enrollment in Algebra II or a higher course in grade 10) or not.

Source: Coursetaking data collected from high schools study participants attended in 2009/10.

Table D-3 shows the number and percentage of students by condition that met each criterion for participation in advanced mathematics course sequence in high school.

Table D-3. Number and Percentage of AR Students Taking Advanced Mathematics Course Sequence in High School

Criterion	Total students (<i>n</i> = 427)		Students from treatment schools (<i>n</i> = 211)		Students from control schools (<i>n</i> = 216)		<i>p</i> -value ^a
	Number	Percent	Number	Percent	Number	Percent	
1) Took course above Algebra I in grade 9 (<i>n</i> = 427)	190	45	124	59	66	31	0.005
2) Passed grade 9 course with grade of C or higher (<i>n</i> = 425)	392	92	194	92	198	92	0.974
3) Enrolled in Algebra II or above for grade 10 (<i>n</i> = 422)	239	57	132	63	107	50	0.034
Met all three criteria and were coded as advanced	176	41	114	54 ^b	62	29	0.007 ^c

Note: Sample includes 427 students (observed data). The sample size of 427 is different from the analytic sample of 440 because this table represents a sensitivity analysis using only observed and not imputed data.

13 students were missing data on criterion 1 (7 from treatment schools, 6 from control schools); 15 students were missing data on criterion 2 (8 from treatment schools, 7 from control schools); 18 students were missing data on criterion 3 (9 from treatment schools, 9 from control schools).

For the second criterion, the grade 9 course refers to any mathematics course, including pre-Algebra and Algebra I.

a. Significance testing was conducted using a two-level hierarchical linear modeling model with students at Level 1 and schools at Level 2. These models included all standard covariates included in the impact models and each criterion as a separate outcome variable.

b. Percentage of AR treatment students who met all three criteria was 53% when averaged across the 10 multiply imputed datasets, however in the 427 observed data points (shown here), the correct percentage is 54%.

c. Corresponds to impact model

Source: Coursetaking data collected from the high schools study participants attended in 2009/10.

Differences in predicted probabilities are presented in the main report to describe the differences in average predicted probabilities between students enrolled in treatment middle schools versus students enrolled in control middle schools (see table 4-3). These probabilities are the average, model-predicted probabilities, controlling for all covariates specified for the model. The logit estimates for the treatment and control groups were converted to average probabilities for each group. These group means and associated standard errors are generated in SAS using PROC

GLIMMIX by requesting the LSMEANS output for the contrast for condition where treatment = 1 and control = 0.

Table D-4 displays the complete results of the benchmark impact analysis model predicting participation in an advanced mathematics course sequence in high school.

Table D-4. Results of Main Impact Model Predicting Likelihood of AR Students Taking Advanced Course Sequence in High School

Variable	Logit coefficient	Standard error	p-value	Odds ratio	95% confidence interval
Intercept	-1.13	0.29	< 0.001	0.32	(0.18, 0.57)
<i>School covariate</i>					
Condition	1.10	0.39	0.007	2.99	(1.38, 6.47)
Medium-size school in Maine	0.33	0.50	0.512	1.39	(0.52, 3.74)
Large-size school in Maine	0.57	0.75	0.454	1.76	(0.39, 7.94)
Small-size school in Vermont	0.64	0.68	0.348	1.90	(0.49, 7.33)
Medium-size school in Vermont	-0.13	0.85	0.877	0.88	(0.16, 4.80)
Large-size school in Vermont	0.28	0.74	0.708	1.32	(0.30, 5.79)
<i>Student covariate</i>					
Female	0.12	0.24	0.612	0.89	(0.56, 1.41)
Receives special education services	-1.90	1.13	0.095	0.15	(0.02, 1.40)
Eligible for free or reduced-price lunch	0.04	0.30	0.885	1.04	(0.58, 1.87)
State mathematics score (standardized) ^a	1.11	0.24	< 0.001	3.05	(1.92, 4.84)

Note: Sample includes 68 schools (35 treatment, 33 control) and 440 AR students (218 treatment, 222 control). Estimates were averaged across 10 multiply imputed datasets. Coursetaking sequences were coded as advanced or not advanced.

a. Because Maine and Vermont use different tests, it was necessary to translate scores into a common metric. The scores were standardized by using the mean and standard deviation of the test scores within each state, including only schools participating in the study.

Source: Coursetaking data collected from high schools study participants attended in 2009/10.

The study team conducted six sensitivity analyses that test the robustness of the observed estimates from the benchmark impact model. These analyses test models with different methods of accounting for students' baseline mathematics achievement, a model with no covariates, a model based on observed (nonimputed) data only as well as a model that tests an alternative nesting structure (with students in treatment schools clustered within online teachers). The results of these sensitivity analyses of the algebra outcome are reported in appendix E (models E.7–E.12).

Secondary Impact Analyses

Analyses of the four secondary research questions estimate the possible side effects of the intervention on AR and N-AR students.

Effects on AR Students' General Mathematics Scores. The first secondary analysis examines the effects of the intervention on AR students' general mathematics scores. Because AR students who have access to online Algebra I could have less exposure to general grade 8 mathematics content than they would have had in the absence of the course, the study team hypothesized that their scores on a general mathematics assessment could be negatively affected. As noted in chapter, 3, the online Algebra I teachers taught significantly more algebra content and significantly less other mathematical content than teachers in control schools taught their high achievers.

For this analysis, researchers calculated the intent-to-treat estimate of the effect of treatment using the general mathematics achievement score (Promise Assessment) at the end of grade 8 as the outcome. They employed the same two-level model presented above for the general mathematics achievement score:

$$GenMath_{ij} = \beta_{0j} + \beta_{1j}(StateMath_{ij} - StateMath..) + \beta_{2j}(SpEd_{ij} - SpEd..) + \beta_{3j}(FRL_{ij} - FRL..) + \beta_{4j}(Female_{ij} - Female..) + \varepsilon_{ij}. \quad (D.3a)$$

$$\begin{aligned} \beta_{0j} = & \gamma_{00} + \gamma_{01} TRT_j + \gamma_{02} (MaineMED_j - MaineMED..) + \gamma_{03} (MaineLG_j - \\ & MaineLG..) + \gamma_{04} (VermontSM_j - VermontSM..) + \gamma_{05} (VermontMED_j - \\ & VermontMED..) + \gamma_{06} (VermontLG_j - VermontLG..) + u_{0j}. \end{aligned} \quad (D.3b)$$

$$\beta_{1j} = \gamma_{10}. \quad (D.3c)$$

$$\beta_{2j} = \gamma_{20}. \quad (D.3d)$$

$$\beta_{3j} = \gamma_{30}. \quad (D.3e)$$

$$\beta_{4j} = \gamma_{40}. \quad (D.3f)$$

Table D-5 displays the results of the impact analysis model predicting achievement in general mathematics at the end of grade 8. There were no significant differences in general mathematics scores for AR students in treatment and control schools.

Table D-5. Results of Impact Model Predicting AR Students' General Mathematics Posttest Scores

Variable	Coefficient	Standard error	p-value	Effect size
Intercept	357.82	1.99	< 0.001	
<i>School covariate</i>				
Condition	3.60	2.80	0.204	0.14
Medium-size school in Maine	8.87	3.46	0.013	
Large-size school in Maine	7.60	4.95	0.130	
Small-size school in Vermont	12.27	5.58	0.032	
Medium-size school in Vermont	11.22	6.32	0.080	
Large-size school in Vermont	17.27	5.64	0.004	
<i>Student covariate</i>				
Female	−6.01	1.92	0.002	
Receives special education services	−7.65	6.46	0.241	
Eligible for free or reduced-price lunch	0.02	2.20	0.993	
State mathematics score (standardized) ^a	18.73	2.48	< 0.001	
	Variance	Chi-squared (degrees of freedom)	p-value	
Residual	363.30			
Level 2 (school)	41.03	102.07 (61)	0.001	
Total variance	404.33			

Note: Sample includes 68 schools (35 treatment, 33 control) and 440 AR students (218 treatment, 222 control). Estimates were averaged across 10 multiply imputed datasets. The effect size was calculated using a pooled standard deviation of the outcome for AR students in treatment and control schools that incorporates both within and between imputation variance (25.22).

a. Because Maine and Vermont use different tests, it was necessary to translate scores into a common metric. The scores were standardized by using the mean and standard deviation of the test scores within each state, including only schools participating in the study.

Source: General mathematics scores on study-administered Promise Assessment posttest.

Effects on N-AR Students' Algebra Scores, General Mathematics Scores, and Planned Coursetaking. The central question of this study concerns the effects of offering online Algebra I in a school that does not otherwise offer Algebra I to grade 8 students. The indirect effects of the intervention on N-AR students are of secondary importance. If there are direct effects on AR students, however, the secondary impact analyses are important for determining whether the intervention is a good investment for schools interested in broadening access to algebra.

The approach to estimating the impact of online Algebra I on N-AR student outcomes mirrors the analytic strategy for estimating the impacts of the intervention on AR students. All models used the N-AR student sample and estimated the effects of school-level treatment status on student-level outcomes. Specifically, equations D.1a–D.1f were used to estimate N-AR students' algebra achievement at the end of grade 8, equations D.2a–D.2f were used to estimate N-AR students' planned grade 9 enrollments, and equations D.3a–D.3f were used to estimate N-AR students' general mathematics achievement at the end of grade 8. Results of the secondary analysis models are presented in tables D-6 through D-9. These analyses reveal no significant differences between N-AR students in treatment schools and control schools on the algebra posttest, general mathematics posttest, or planned grade 9 enrollments.

All analyses on the N-AR sample were conducted using 10 multiply imputed datasets; estimates presented in this appendix are averages based on the 10 different datasets. For more information on the multiple imputation of missing data, see appendix F.

Table D-6. Results of Impact Model Predicting N–AR Students’ Algebra Posttest Scores

Variable	Coefficient	Standard error	p-value	Effect size
Intercept	429.80	1.01	< 0.001	
<i>School covariate</i>				
Condition	0.96	1.25	0.443	0.06
Medium-size school in Maine	–4.85	1.91	0.014	
Large-size school in Maine	–5.81	2.41	0.019	
Small-size school in Vermont	–7.93	2.95	0.010	
Medium-size school in Vermont	–5.76	3.01	0.060	
Large-size school in Vermont	–5.09	2.33	0.033	
<i>Student covariate</i>				
Female	1.79	0.90	0.047	
Receives special education services	–3.02	1.51	0.051	
Eligible for free or reduced-price lunch	–1.34	0.86	0.119	
State mathematics score (standardized) ^a	3.87	0.65	< 0.001	
Chi-squared				
	Variance	(degrees of freedom)	p-value	
Residual	213.85			
Level 2 (school)	8.23	106.12 (57)	< 0.001	
Total variance	222.08			

Note: Sample included 68 schools (35 treatment, 33 control) and 1,445 N–AR students (744 treatment, 701 control schools); 4 control schools had no N–AR students. Estimates were averaged across 10 multiply imputed datasets. The effect size was calculated using a pooled standard deviation of the outcome for N-AR students in treatment and control schools that incorporates both within and between imputation variance (16.94).

- a. Because Maine and Vermont use different tests, it was necessary to translate scores into a common metric. The scores were standardized by using the mean and standard deviation of the test scores within each state, including only schools participating in the study.

Source: Algebra scores on study-administered Promise Assessment posttest.

Table D-7. Results of Impact Model Predicting N–AR Students’ General Mathematics Posttest Scores

Variable	Coefficient	Standard error	p-value	Effect size
Intercept	324.21	1.96	< 0.001	
<i>School covariate</i>				
Condition	0.65	2.41	0.789	0.02
Medium-size school in Maine	1.29	3.38	0.704	
Large-size school in Maine	–4.97	4.42	0.266	
Small-size school in Vermont	2.22	5.21	0.671	
Medium-size school in Vermont	2.24	5.66	0.694	
Large-size school in Vermont	8.90	4.87	0.072	
<i>Student covariate</i>				
Female	–2.59	1.41	0.066	
Receives special education services	–11.46	2.27	< 0.001	
Eligible for free or reduced-price lunch	–3.43	1.45	0.018	
State mathematics score (standardized) ^a	13.78	0.98	< 0.001	
Chi-squared (degrees of freedom)				
	Variance		p-value	
Residual	583.17			
Level 2 (school)	39.54	133.04 (57)	< 0.001	
Total variance	622.71			

Note: Sample includes 68 schools (35 treatment, 33 control) and 1,445 N–AR students (744 treatment, 701 control); 4 control schools had no N–AR students. Estimates were averaged across 10 multiply imputed datasets. The effect size was calculated using a pooled standard deviation of the outcome for N–AR students in treatment and control schools that incorporates both within and between imputation variance (31.44)..

a. Because Maine and Vermont use different tests, it was necessary to translate scores into a common metric. The scores were standardized by using the mean and standard deviation of the test scores within each state, including only schools participating in the study.

Source: General mathematics scores on study-administered Promise Assessment posttest.

Table D-8 presents the descriptive statistics that mirror the secondary impact analyses for N–AR students in table 4-5 of the main text. Multiply imputed percentages presented in table D-8 are averaged across the 10 imputed datasets. The results indicate that among N–AR students, 76% students in treatment schools and 66% in control schools planned to enroll in an intermediate mathematics course in grade 9, a difference that was not statistically significant.

Table D-8. Percentage of Grade 8 N–AR Students Who Planned to Enroll in Intermediate Mathematics Course in Grade 9

Planned Grade 9 course	Students in treatment schools	Students in control schools	All N–AR students
Intermediate (course equivalent to or above Algebra I)	76.0	66.2	71.2
Not intermediate (course below Algebra I)	24.0	33.8	28.8

Note: Sample includes 68 schools (35 treatment, 33 control) and 1,445 N–AR students (744 treatment, 701 control); control schools had N–AR students. Estimates were averaged across 10 multiply imputed datasets. Twenty-three N–AR students planned to enroll in a grade 9 course above Algebra 1, including 13 students (2%) from control schools and 10 students (1%) from treatment schools

Source: Planned courses indicated by study students at end of Grade 8.

Table D-9 presents the complete results of the impact model presented in table 4-5, a model predicting N–AR students’ plans to follow an intermediate mathematics course sequence in grade 9.

Table D-9. Results of Impact Model Predicting N–AR Students’ Planned Grade 9 Coursetaking

Variable	Logit coefficient	Standard error	p-value	Odds ratio	95% confidence interval
Intercept	1.03	0.35	0.005	2.80	(0.38, 5.67)
<i>School covariate</i>					
Condition	0.78	0.46	0.099	2.18	(0.86, 5.51)
Medium-size school in Maine	1.37	0.56	0.018	3.95	(1.28, 12.16)
Large-size school in Maine	0.72	0.87	0.416	2.05	(0.36, 11.73)
Small-size school in Vermont	–0.46	0.78	0.559	0.63	(0.13, 3.02)
Medium-size school in Vermont	–1.61	0.92	0.087	0.20	(0.03, 1.27)
Large-size school in Vermont	0.22	0.84	0.799	1.24	(0.23, 6.69)
<i>Student covariate</i>					
Female	0.08	0.18	0.637	0.92	(0.65, 1.31)
Receives special education services	–1.35	0.24	< 0.001	0.26	(0.16, 0.42)
Eligible for free or reduced-price lunch	–0.59	0.16	0.001	0.56	(0.40, 0.77)
State mathematics score (standardized) ^a	1.54	0.17	< 0.001	4.66	(3.32, 6.54)

Note: Sample includes 68 schools (35 treatment, 33 control) and 1,445 N–AR students (744 treatment, 701 control); 4 control schools had no N–AR students. Estimates were averaged across 10 multiply imputed datasets. Coursetaking sequences were coded as advanced or not advanced.

a. Because Maine and Vermont use different tests, it was necessary to translate scores into a common metric. The scores were standardized by using the mean and standard deviation of the test scores within each state, including only schools participating in the study.

Source: Planned courses indicated by study students at end of Grade 8.

Ten sensitivity analyses were conducted to test the robustness of the findings for N–AR students’ algebra achievement and planned grade 9 coursetaking. For each outcome, these sensitivity analyses tested three models with different methods of accounting for students’ baseline mathematics achievement, a model with no covariates, and a model based on observed (nonimputed) data only. The results of these sensitivity analyses are reported in appendix E (see models E.13–E.17 for the algebra outcome and models E.18–E.22 for the grade 9 planned coursetaking outcome).

Exploratory Analyses

The two exploratory research questions were analyzed from 10 multiply imputed datasets. The model estimates presented are averages based on the 10 datasets. For more information on the multiple imputation of missing data, see appendix F.

Exploratory Research Question 1

To estimate the impact of access to online Algebra I on AR students’ planned coursetaking, the study team used the same analytic strategy used to estimate the impact of the intervention on AR students’ high school coursetaking. Using the AR student sample, researchers estimated the effect of school-level treatment status on students’ planned grade 9 enrollments, collected at the end of grade 8, with the models outlined in equations D.2a–D.2f.

Descriptive analyses showed that among AR students, 58% in treatment schools and just 24% in control schools initially registered for an advanced grade 9 course (table D-10).⁵⁵

Table D-10. Percentage of Grade 8 AR Students Who Planned to Enroll in Advanced Mathematics Course in Grade 9

Planned course	Students in treatment schools	Students in control schools	All AR students
Algebra I or below	42.0	75.7	59.0
Above Algebra I	58.0	24.3	41.0

Note: Sample includes 68 schools (35 treatment, 33 control) and 440 AR students (218 treatment, 222 control). Estimates were averaged across 10 multiply imputed datasets.

Source: Planned courses indicated by study students at end of Grade 8.

Table D-11 displays the complete results of the model predicting AR students' plans to follow an advanced mathematics course sequence in grade 9.

Table D-11. Results of Impact Model Predicting AR Students' Planned Grade 9 Coursetaking

Variable	Logit coefficient	Standard error	p-value	Odds ratio	95% confidence interval
Intercept	-1.54	0.46	0.002	0.21	(0.09, 0.54)
<i>School covariate</i>					
Condition	1.78	0.61	0.005	5.96	(1.76, 20.19)
Medium-size school in Maine	0.13	0.72	0.860	1.14	(0.27, 4.83)
Large-size school in Maine	-0.26	1.19	0.825	0.77	(0.07, 8.23)
Small-size school in Vermont	1.21	0.99	0.228	3.35	(0.46, 24.22)
Medium-size school in Vermont	-0.62	1.32	0.640	0.54	(0.04, 7.54)
Large-size school in Vermont	-0.51	1.19	0.670	0.60	(0.06, 6.45)
<i>Student covariate</i>					
Female	0.17	0.28	0.533	0.84	(0.49, 1.45)
Receives special education services	-0.45	0.98	0.649	0.64	(0.09, 4.42)
Eligible for free or reduced-price lunch	-0.35	0.32	0.282	0.71	(0.38, 1.33)
State mathematics score (standardized) ^a	1.07	0.30	0.001	2.91	(1.62, 5.22)

Note: Sample includes 68 schools (35 treatment, 33 control) and 440 AR students (218 treatment, 222 control). Estimates were averaged across 10 multiply imputed datasets. Coursetaking sequences were coded as advanced or not advanced.

a. Because Maine and Vermont use different tests, it was necessary to translate scores into a common metric. The scores were standardized by using the mean and standard deviation of the test scores within each state, including only schools participating in the study.

Source: Planned courses indicated by study students at end of Grade 8.

These results are consistent with the main results on AR students' high school coursetaking, and together they show that students with access to online Algebra I in grade 8 were more likely to both initially enroll in an advanced grade 9 course at the end of grade 8 (planned grade 9 coursetaking) and to continue to follow an advanced course sequence as of the end of grade 9 (actual coursetaking in grade 9 and planned coursetaking in grade 10).

⁵⁵ The percentages of students who completed an advanced course in grade 9 were 59% for treatment group students and 31% for control group students (see table D-3).

Exploratory Research Question 2

To estimate the impact of online Algebra I on AR students' likelihood of doubling up on mathematics courses in grade or grade 10, researchers used the same impact model (outlined in equations 2a–2f) with one exception. The model for doubling up on mathematics courses did not include students' special education status as a covariate at level 1 because no students with special education status doubled up. Results for exploratory question 2 are presented in Tables D-12 and D-13.

Table D-12 presents the descriptive results for doubling up by condition. As shown below, 14% of AR students from treatment middle schools doubled-up on mathematics courses in grade 9 or 10, compared with 29% of AR students from control middle schools.

Table D-12. Percentage of AR Students Who Double Up on Mathematics Courses in Grade 9 or 10

Coursetaking pattern	Students from treatment schools	Students from control schools	All AR students
Did not double up in grade 9 or 10	85.6	70.8	78.2
Doubled up in grade 9 or 10	14.4	29.2	21.8

Note: Sample includes 68 schools (35 treatment, 33 control) and 440 AR students (218 treatment, 222 control). Estimates were averaged across 10 multiply imputed datasets. Doubling up was coded as AR students who took two or more mathematics courses in grade 9 or 10.

Source: Coursetaking data collected from high schools study students attended in 2009/10.

Table D-13 displays the complete results of the model predicting AR students' likelihood of doubling up on mathematics courses in grade 9 or 10.

Table D-13. Results of Impact Model Predicting AR Students' Likelihood of Doubling Up on Full-Year Mathematics Courses in Grade 9 or 10

Variable	Logit coefficient	Standard error	p-value	Odds ratio	95% confidence interval
Intercept	-1.27	0.33	< 0.001	0.28	(0.15, 0.54)
<i>School covariate</i>					
Condition	-1.07	0.49	0.033	0.34	(0.13, 0.92)
Medium-size school in Maine	-0.24	0.61	0.700	0.79	(0.23, 2.69)
Large-size school in Maine	-0.39	0.96	0.685	0.68	(0.10, 4.58)
Small-size school in Vermont	-0.33	0.88	0.706	0.72	(0.12, 4.16)
Medium-size school in Vermont	1.18	0.96	0.225	3.25	(0.48, 22.18)
Large-size school in Vermont	1.64	0.82	0.050	5.14	(1.00, 26.46)
<i>Student covariate</i>					
Female	-0.18	0.30	0.536	1.20	(0.67, 2.15)
Eligible for free or reduced-price lunch	-0.10	0.37	0.777	0.90	(0.44, 1.85)
State mathematics score (standardized)	0.35	0.26	0.177	1.42	(0.85, 2.35)

Note: Sample includes 68 schools (35 treatment, 33 control) and 440 AR students (218 treatment, 222 control). Estimates were averaged across 10 multiply imputed datasets. Doubling up was coded as 1 for AR students who took 3 or more mathematics courses in grade 9 or 10 and 0 for students who took 2 or fewer mathematics courses.

a. Because Maine and Vermont use different tests, it was necessary to translate scores into a common metric. The scores were standardized by using the mean and standard deviation of the test scores within each state, including only schools participating in the study.

Source: Coursetaking data collected from high schools study students attended in 2009/10.

These results suggest that AR students in controls schools who do not have access to Algebra I in grade 8 were more likely to double up on mathematics courses in grade 9 or 10 than students in treatment schools, possibly to get “on track” for an advanced course sequence.

APPENDIX E: SENSITIVITY ANALYSES

This appendix presents the models used to conduct sensitivity analyses. As in appendix D, this appendix presents coefficients and standard errors for all of the variables in each model, including student- and school-level covariates. The results for coursetaking sensitivity analyses also include corresponding odds ratios and 95 percent confidence intervals for each predictor.

Impact of Intervention on AR Students' Algebra Scores

To determine the robustness of the impact estimates based on the benchmark impact model for AR students' algebra posttest scores, the study team conducted the following sensitivity analyses:

- Model E.1 includes prior state mathematics assessment scores and study-administered pretest scores at Level 1 (grand mean centered).
- Model E.2 replaces students' prior state mathematics assessment scores with their study-administered pretest scores at Level 1 (grand mean centered).
- Model E.3 does not adjust for baseline mathematics achievement by excluding students' prior state mathematics assessment scores at Level 1.
- Model E.4 excludes all covariates at Level 1 and Level 2.
- Model E.5 tests the benchmark impact model on observed (nonimputed) data only.
- Model E.6 combines the 34 schools that share an online teacher into 8 “pseudo-schools” for treatment students and uses the standard school for all control students.
- Model E.7 includes a covariate that captures time spent on the algebra posttest at Level 1 (grand-mean centered).

Sensitivity Analyses Using Different Methods of Adjusting for Baseline Mathematics Achievement

The first three sensitivity analyses examined the extent to which the estimate of the impact of the intervention is robust to different ways of controlling for baseline mathematics achievement. In three models researchers tested whether the treatment effect is robust when (a) the study-administered Promise Assessment pretest scores is added to state mathematics scores, (b) students' baseline state mathematics scores are replaced with their pretest scores, and (c) both measures of prior mathematics achievement are excluded. As detailed in chapter 2, the study-administered pretest was endogenous to the study—that is, it was administered after random assignment and after implementation of the intervention had begun in treatment schools. Additionally, students in treatment and control schools differed significantly in their pretest scores at baseline. Scores on the state mathematics assessments from the previous year, however, were exogenous to the study and could not have been affected by the presence of the study or the intervention. Students in treatment and control schools did not differ in their prior state mathematics scores at baseline.

Sensitivity Analyses for AR Students' Algebra Scores

All of the sensitivity analyses are consistent with the results of the benchmark impact analysis model, where the estimated impact was 5.53 ($p = 0.001$, effect size = 0.39) (table E-1). In each analysis, the effect of condition on AR students' algebra scores at the end of grade 8 was statistically significant (using an alpha value of 0.025 that accounts for multiple comparisons), with AR students in treatment schools outperforming their counterparts in control schools. In model E.2, where student's state mathematics assessment scores are replaced with their study-administered pretest scores, the treatment effect is attenuated: the effect size (0.29) is 26% smaller than the effect size reported for the impact model (0.39). The significant difference by condition on the pretest may explain this attenuation.

Table E-1. Summary of Sensitivity Analyses Testing Robustness of Effect of Condition on AR Students' Algebra Posttest Scores

Model	Estimated impact (standard error)	<i>p</i>-value	Effect size
E.1 includes prior state mathematics and study-administered pretest scores as covariates at Level 1 (grand-mean centered)	5.05 (1.52)	0.002	0.37
E.2 replaces state mathematics with study-administered pretest scores as covariates at Level 1	4.01 (1.47)	0.009	0.29
E.3 excludes state mathematics and study-administered pretest scores as covariates at Level 1	5.35 (1.83)	0.005	0.39
E.4 excludes all covariates at Level 1 and Level 2	5.17 (1.82)	0.007	0.38
E.5 tests benchmark impact model using observed (nonimputed) data only	5.59 (1.51)	0.001	0.45 ^a
E.6 clusters treatment students who share an online teacher into "pseudo-schools" and control students by their standard school	5.55 (1.80)	0.004	0.41
E.7 includes a covariate that captures time spent on the algebra posttest (grand-mean centered)	4.79 (1.47)	0.002	0.35

Note: Sample for all models except E.5 includes 68 schools (35 treatment, 33 control) and 440 AR students (218 treatment, 222 control); estimates are averaged across 10 multiply imputed datasets. Model E.5 includes 68 schools (35 treatment, 33 control) and 430 AR students; 10 students were missing data on the outcome or 1 covariate (estimates are based on observed data only). The sample size of 430 is different from the analytic sample of 440 because this model uses only observed (nonimputed) data. Model E.6 excludes state by size blocking covariates at Level 2, given that they do not apply to online teachers. Effect sizes were calculated using a pooled standard deviation of the outcome for AR students in treatment and control schools that incorporates both within and between imputation variance (13.78).

a. The Hedges' g effect size was calculated using a pooled standard deviation of the outcome for AR students in treatment and control schools (13.77).

Source: Algebra scores on study-administered Promise Assessment posttests.

Model E.1

Model E.1 is identical to the model estimated for the benchmark analysis, except that students' study-administered pretest scores is added as an adjustment for baseline mathematics achievement at Level 1. As was the case in the benchmark analysis, all covariates except the treatment indicator were centered on the grand mean.

$$\begin{aligned} Algebra_{ij} = & \beta_{0j} + \beta_{1j} (StateMath_{ij} - StateMath..) + \beta_{2j} (Pretest_{ij} - Pretest..) + \beta_{3j} (SpEd_{ij} - \\ & SpEd..) + \beta_{4j} (FRL_{ij} - FRL..) + \beta_{5j} (Female_{ij} - Female..) + \varepsilon_{ij}. \end{aligned} \quad (E.1a)$$

$$\begin{aligned} \beta_{0j} = & \gamma_{00} + \gamma_{01} TRT_j + \gamma_{02} (MaineMED_j - MaineMED..) + \gamma_{03} (MaineLG_j - \\ & MaineLG..) + \gamma_{04} (VermontSM_j - VermontSM..) + \gamma_{05} (VermontMED_j - \\ & VermontMED..) + \gamma_{06} (VermontLG_j - VermontLG..) + u_{0j}. \end{aligned} \quad (E.1b)$$

$$\beta_{1j} = \gamma_{10}. \quad (E.1c)$$

$$\beta_{2j} = \gamma_{20}. \quad (E.1d)$$

$$\beta_{3j} = \gamma_{30}. \quad (E.1e)$$

$$\beta_{4j} = \gamma_{40}. \quad (E.1f)$$

$$\beta_{5j} = \gamma_{50}. \quad (E.1g)$$

Table E-2. Results of Sensitivity Model 1: Adding Study-Administered Pretest Scores at Level 1 (Grand Mean Centered)

Variable	Coefficient	Standard error	p-value	Effect size
Intercept	441.93	1.09	< 0.001	
<i>School covariate</i>				
Condition	5.05	1.52	0.002	0.37
Medium-size school in Maine	1.30	1.93	0.501	
Large-size school in Maine	2.72	2.66	0.311	
Small-size school in Vermont	4.60	2.99	0.129	
Medium-size school in Vermont	2.24	3.42	0.515	
Large-size school in Vermont	2.54	2.94	0.391	
<i>Student covariate</i>				
Female	0.49	1.15	0.669	
Receives special education services	−10.38	3.45	0.003	
Eligible for free or reduced-price lunch	2.08	1.29	0.107	
Pretest	0.07	0.04	0.119	
State mathematics score (standardized) ^a	8.58	1.56	< 0.001	
	Variance	Chi-squared (degrees of freedom)	p-value	
Residual	127.15			
Level 2 (school)	9.46	83.18 (61)	0.031	
Total variance	136.61			

Note: Sample includes 68 schools (35 treatment, 33 control) and 440 AR students (218 treatment, 222 control). Estimates were averaged across 10 multiply imputed datasets. The effect size was calculated using a pooled standard deviation of the outcome for AR students in treatment and control schools that incorporates both within and between imputation variance (13.78).

a. Because Maine and Vermont use different tests, it was necessary to translate scores into a common metric. The scores were standardized by using the mean and standard deviation of the test scores within each state, including only schools participating in the study.

Source: Algebra scores on study-administered Promise Assessment posttest.

Model E.2

Model E.2 is identical to the model estimated for the benchmark analysis, except that students' state mathematics assessment scores are replaced with their scores on the study-administered pretest at Level 1. As was the case in the benchmark analysis, all covariates except the treatment indicator were centered on the grand mean.

$$\text{Algebra}_{ij} = \beta_{0j} + \beta_{1j} (\text{Pretest}_{ij} - \text{Pretest}_{..}) + \beta_{2j} (\text{SpEd}_{ij} - \text{SpEd}_{..}) + \beta_{3j} (\text{FRL}_{ij} - \text{FRL}_{..}) + \beta_{4j} (\text{Female}_{ij} - \text{Female}_{..}) + \varepsilon_{ij}. \quad (\text{E.2a})$$

$$\begin{aligned} \beta_{0j} = & \gamma_{00} + \gamma_{01} \text{TRT}_j + \gamma_{02} (\text{MaineMED}_j - \text{MaineMED}_{..}) + \gamma_{03} (\text{MaineLG}_j - \\ & \text{MaineLG}_{..}) + \gamma_{04} (\text{VermontSM}_j - \text{VermontSM}_{..}) + \gamma_{05} (\text{VermontMED}_j - \\ & \text{VermontMED}_{..}) + \gamma_{06} (\text{VermontLG}_j - \text{VermontLG}_{..}) + u_{0j}. \end{aligned} \quad (\text{E.2b})$$

$$\beta_{1j} = \gamma_{10}. \quad (\text{E.2c})$$

$$\beta_{2j} = \gamma_{20}. \quad (\text{E.2d})$$

$$\beta_{3j} = \gamma_{30}. \quad (\text{E.2e})$$

$$\beta_{4j} = \gamma_{40}. \quad (\text{E.2f})$$

A statistically significant and positive coefficient γ_{01} for treatment indicates that the effect of the online course on algebra scores is robust to replacing students' state mathematics scores with their pretest scores as a different (although endogenous) measure of baseline mathematics achievement (table E-3).

Table E-3. Results of Sensitivity Model 2: Replacing Prior State Mathematics Assessment Scores with Study-Administered Pretest Scores at Level 1

Variable	Coefficient	Standard error	p-value	Effect size
Intercept	442.56	1.09	< 0.001	
<i>School covariate</i>				
Condition	4.01	1.47	0.009	0.29
Medium-size school in Maine	1.17	1.99	0.557	
Large-size school in Maine	3.09	2.67	0.252	
Small-size school in Vermont	4.80	2.72	0.082	
Medium-size school in Vermont	0.25	3.34	0.942	
Large-size school in Vermont	1.52	2.54	0.550	
<i>Student covariate</i>				
Female	-1.49	1.21	0.220	
Receives special education services	-9.70	3.29	0.004	
Eligible for free or reduced-price lunch	1.51	1.32	0.256	
Pretest	0.23	0.03	< 0.001	
	Variance	Chi-squared (degrees of freedom)	p-value	
Residual	147.57			
Level 2 (school)	7.65	77.71 (61)	0.073	
Total variance	155.22			

Note: Sample includes 68 schools (35 treatment, 33 control) and 440 AR students (218 treatment, 222 control). Estimates were averaged across 10 multiply imputed datasets. The effect size was calculated using a pooled standard deviation of the outcome for AR students in treatment and control schools that incorporates both within and between imputation variance (13.78).

Source: Algebra scores on study-administered Promise Assessment posttest.

Model E.3

Model E.3 is identical to the model estimated for the benchmark analysis, except that the study team excluded students' state mathematics assessment scores at Level 1 and controlled only for student demographic characteristics (gender, eligibility for free or reduced priced lunch, special education status) at Level 1 and state by size blocking variables (used for random assignment) at Level 2. As was the case in the benchmark analysis, all covariates except the treatment indicator were centered on the grand mean.

$$Algebra_{ij} = \beta_{0j} + \beta_{1j} (SpEd_{ij} - SpEd..) + \beta_{2j} (FRL_{ij} - FRL..) + \beta_{3j} (Female_{ij} - Female..) + \varepsilon_{ij}. \quad (E.3a)$$

$$\begin{aligned} \beta_{0j} = & \gamma_{00} + \gamma_{01} TRT_j + \gamma_{02} (MaineMED_j - MaineMED..) + \gamma_{03} (MaineLG_j - \\ & MaineLG..) + \gamma_{04} (VermontSM_j - VermontSM..) + \gamma_{05} (VermontMED_j - \\ & VermontMED..) + \gamma_{06} (VermontLG_j - VermontLG..) + u_{0j}. \end{aligned} \quad (E.3b)$$

$$\beta_{1j} = \gamma_{10}. \quad (E.3c)$$

$$\beta_{2j} = \gamma_{20}. \quad (E.3d)$$

$$\beta_{3j} = \gamma_{30}. \quad (E.3e)$$

A statistically significant and positive coefficient γ_{01} for treatment indicates that the effect of the online course on algebra scores is robust when not adjusting for students' mathematics achievement at baseline (that is, excluding state mathematics and pretest scores) (table E-4).

Table E-4. Results of Sensitivity Model 3: Excluding Students' Prior State Mathematics Assessment Scores at Level 1

Variable	Coefficient	Standard error	p-value	Effect size
Intercept	441.83	1.34	< 0.001	
<i>School covariate</i>				
Condition	5.35	1.83	0.005	0.39
Medium-size school in Maine	1.88	2.39	0.436	
Large-size school in Maine	2.08	3.47	0.551	
Small-size school in Vermont	5.08	3.27	0.125	
Medium-size school in Vermont	-0.41	4.05	0.921	
Large-size school in Vermont	3.79	3.23	0.246	
<i>Student covariate</i>				
Female	-0.06	1.27	0.963	
Receives special education services	-13.34	3.50	< 0.001	
Eligible for free or reduced-price lunch	0.75	1.41	0.594	
	Variance	Chi-squared (degrees of freedom)	p-value	
Residual	162.87			
Level 2 (school)	22.09	112.36 (61)	< 0.001	
Total variance	184.96			

Note: Sample includes 68 schools (35 treatment, 33 control) and 440 AR students (218 treatment, 222 control). Estimates were averaged across 10 multiply imputed datasets. The effect size was calculated using a pooled standard deviation of the outcome for AR students in treatment and control schools that incorporates both within and between imputation variance (13.78).

Source: Algebra scores on study-administered Promise Assessment posttest.

Model E.4

To examine the relationship between the effect of the intervention on algebra scores and the covariates specified in the benchmark impact model, model E.4 tests the treatment effect while excluding students' state mathematics assessment scores and their demographic characteristics (gender, eligibility for free or reduced priced lunch, special education status) at Level 1 and state by size blocking variables (used for random assignment) at Level 2.

$$Algebra_{ij} = \beta_{0j} + \varepsilon_{ij}. \quad (E.4a)$$

$$\beta_{0j} = \gamma_{00} + \gamma_{01} TRT_j + u_{0j}. \quad (E.4b)$$

A statistically significant and positive coefficient γ_{01} for treatment indicates that the effect of the online course on algebra scores is robust when not adjusting for student-level variability in baseline mathematics achievement and demographic characteristics and school-level variability across size and state (table E-5).

Table E-5. Results of Sensitivity Model 4: Excluding All Covariates at Level 1 or 2

Variable	Coefficient	Standard error	p-value	Effect size
Intercept	442.22	1.30	< 0.001	
<i>School covariate</i>				
Condition	5.17	1.82	0.007	0.38
	Variance	Chi-squared (degrees of freedom)	p-value	
Residual	166.33			
Level 2 (school)	23.25	125.08 (66)	< 0.001	
Total variance	189.58			

Note: Sample includes 68 schools (35 treatment, 33 control) and 440 AR students (218 treatment, 222 control). Estimates were averaged across 10 multiply imputed datasets. The effect size was calculated using a pooled standard deviation of the outcome for AR students in treatment and control schools that incorporates both within and between imputation variance (13.78).

Source: Algebra scores on study-administered Promise Assessment posttest.

Model E.5

To examine whether the effect of the intervention on algebra posttest scores is sensitive to the missing data approach (multiple imputation, described in appendix F), model E.5 tests the benchmark impact model using observed (nonimputed) data only, excluding cases that were missing data for the algebra posttest or a covariate in the analytic model (2.3% of all cases). The loss of data reduces the size of the available sample and associated statistical power and may introduce bias into the parameter estimate.⁵⁶ However, the impact models include covariates found to be related to missing values, such as gender, eligibility for free or reduced-price lunch, state mathematics assessment scores, and school-level state and size blocking covariates. Inclusion of these covariates may help reduce bias caused by missing data.⁵⁷ As was the case in the benchmark analysis, all covariates except the treatment indicator were centered on the grand mean.

$$\begin{aligned} Algebra_{ij} = & \beta_{0j} + \beta_{1j} (StateMath_{ij} - StateMath..) + \beta_{2j} (SpEd_{ij} - SpEd..) + \beta_{3j} (FRL_{ij} - \\ & FRL..) + \beta_{4j} (Female_{ij} - Female..) + \varepsilon_{ij}. \end{aligned} \quad (E.5a)$$

$$\begin{aligned} \beta_{0j} = & \gamma_{00} + \gamma_{01} TRT_j + \gamma_{02} (MaineMED_j - MaineMED..) + \gamma_{03} (MaineLG_j - \\ & MaineLG..) + \gamma_{04} (VermontSM_j - VermontSM..) + \gamma_{05} (VermontMED_j - \\ & VermontMED..) + \gamma_{06} (VermontLG_j - VermontLG..) + u_{0j}. \end{aligned} \quad (E.5b)$$

$$\beta_{1j} = \gamma_{10}. \quad (E.5c)$$

$$\beta_{2j} = \gamma_{20}. \quad (E.5d)$$

$$\beta_{3j} = \gamma_{30}. \quad (E.5e)$$

$$\beta_{4j} = \gamma_{40}. \quad (E.5f)$$

A statistically significant and positive coefficient γ_{01} for treatment indicates that the effect of the online course on algebra scores is robust to the method of handling missing data (multiply imputed versus observed only) (table E-6).

⁵⁶ This loss of data could lead to larger standard errors, wider confidence intervals, and loss of power in testing hypotheses.

⁵⁷ When the listwise approach is used, it is usually recommended to include in the regression used to estimate impact covariates that may influence both the outcome and the probability of having missing data on outcomes (Puma et al. 2009).

Table E-6. Results of Sensitivity Model 5: Including Observed (Nonimputed) Data Only

Variable	Coefficient	Standard error	p-value	Effect size
Intercept	441.76	1.12	< 0.001	
<i>School covariate</i>				
Condition	5.59	1.51	0.001	0.41 ^a
Medium-size school in Maine	1.49	2.01	0.461	
Large-size school in Maine	2.73	2.85	0.341	
Small-size school in Vermont	4.49	2.77	0.110	
Medium-size school in Vermont	-0.14	3.39	0.968	
Large-size school in Vermont	1.60	2.66	0.548	
<i>Student covariate</i>				
Female	-0.25	1.14	0.827	
Receives special education services	-9.56	3.15	0.003	
Eligible for free or reduced-price lunch	2.37	1.27	0.062	
State mathematics score (standardized) ^b	10.12	0.95	< 0.001	
	Variance	Chi-squared (degrees of freedom)	p-value	
Residual	131.15			
Level 2 (school)	12.23	90.70 (61)	0.008	
Total variance	143.38			

AR is algebra ready.

Note: Sample includes 68 schools (35 treatment, 33 control) and 430 AR students (215 treatment, 215 control); 10 students were missing data on the outcome or 1 covariate. The sample size of 430 is different from the analytic sample of 440 because this table represents a sensitivity analysis using only observed (not imputed) data.

- The Hedges' g effect size was calculated using a pooled standard deviation of the outcome for AR students in treatment and control schools (13.77).
- Because Maine and Vermont use different tests, it was necessary to translate scores into a common metric. The scores were standardized by using the mean and standard deviation of the test scores within each state, including only schools participating in the study.

Source: Algebra scores on study-administered Promise Assessment posttest.

Model E.6

The outcomes for treatment students in schools that share a common online teacher may be affected in similar ways by specific qualities and background of the online teacher (for example, the teacher's knowledge or experience teaching online). Consequently, students in treatment schools that share an online teacher are not completely independent. To examine whether the observed treatment effect on algebra scores in the benchmark analysis is robust to the clustering of students within online teachers, researchers tested a model similar to the model estimated for the benchmark analysis, with two exceptions. First, treatment students were clustered at Level 2 within the eight online Algebra I teachers, and control students were clustered within their standard schools. Second, because school-level covariates (school state and size) do not apply to online teachers, only the treatment indicator was included in this model at Level 2. As was the case in the benchmark analysis, all covariates except the treatment indicator were centered on the grand mean.

$$Algebra_{ij} = \beta_{0j} + \beta_{1j}(StateMath_{ij} - StateMath..) + \beta_{2j}(SpEd_{ij} - SpEd..) + \beta_{3j}(FRL_{ij} - FRL..) + \beta_{4j}(Female_{ij} - Female..) + \varepsilon_{ij}. \quad (E.6a)$$

$$\beta_{0j} = \gamma_{00} + \gamma_{01} TRT_j + u_{0j}. \quad (E.6b)$$

$$\beta_{1j} = \gamma_{10}. \quad (\text{E.6c})$$

$$\beta_{2j} = \gamma_{20}. \quad (\text{E.6d})$$

$$\beta_{3j} = \gamma_{30}. \quad (\text{E.6e})$$

$$\beta_{4j} = \gamma_{40}. \quad (\text{E.6f})$$

A statistically significant and positive coefficient γ_{01} for treatment indicates that the effect of the online course on algebra scores is robust to the unit of clustering at Level 2 for treatment students by using online teacher instead of school (table E-7).

Table E-7. Results of Sensitivity Model 6: Using Pseudo-School Level 2 Clusters in Estimation of AR Students' Algebra Scores

Variable	Coefficient	Standard error	p-value	Effect size
Intercept	441.95	1.05	< 0.001	
<i>School covariate</i>				
Condition	5.55	1.80	0.004	0.40
<i>Student covariate</i>				
Female	-0.17	1.13	0.884	
Receives special education services	-11.04	3.60	0.003	
Eligible for free or reduced-price lunch	1.76	1.29	0.171	
State mathematics score (standardized) ^a	9.92	1.11	< 0.001	
	Variance	Chi-squared (degrees of freedom)	p-value	
Residual	130.01			
Level 2 (school)	9.44	65.49 (45)	0.024	
Total variance	139.45			

AR is algebra ready.

Note: Sample includes 68 schools (35 treatment, 33 control) and 440 AR students (218 treatment, 222 control). Estimates were averaged across 10 multiply imputed datasets. The effect size was calculated using a pooled standard deviation of the outcome for AR students in treatment and control schools that incorporates both within and between imputation variance (13.78).

a. Because Maine and Vermont use different tests, it was necessary to translate scores into a common metric. The scores were standardized by using the mean and standard deviation of the test scores within each state, including only schools participating in the study.

Source: Algebra scores on study-administered Promise Assessment posttest.

Model E.7

Model E.7 is identical to the model estimated for the benchmark analysis, except that students' time spent on the algebra posttest is added as a covariate at Level 1. As noted in Chapter 2 and Appendix B, there was an observed difference by condition in the amount of time spent by AR students on the computer-adaptive mathematics pretest, where students in treatment schools spent significantly more time than students in control schools. The difference in time spent on the algebra posttest was not significantly different by condition but time spent on the test could nevertheless account for all or part of the observed treatment effect. This sensitivity analysis was conducted to examine this possibility. As was the case in the benchmark analysis, all covariates except the treatment indicator were centered on the grand mean.

$$\begin{aligned} Algebra_{ij} = & \beta_{0j} + \beta_{1j} (StateMath_{ij} - StateMath..) + \beta_{2j} (SpEd_{ij} - SpEd..) + \beta_{3j} (FRL_{ij} - \\ & FRL..) + \beta_{4j} (Female_{ij} - Female..) + \beta_{5j} (Time\ on\ Algebra\ Posttest_{ij} - Time\ on \\ & Algebra\ Posttest..) + \varepsilon_{ij}. \end{aligned} \quad (E.7a)$$

$$\begin{aligned} \beta_{0j} = & \gamma_{00} + \gamma_{01} TRT_j + \gamma_{02} (MaineMED_j - MaineMED..) + \gamma_{03} (MaineLG_j - \\ & MaineLG..) + \gamma_{04} (VermontSM_j - VermontSM..) + \gamma_{05} (VermontMED_j - \\ & VermontMED..) + \gamma_{06} (VermontLG_j - VermontLG..) + u_{0j}. \end{aligned} \quad (E.7b)$$

$$\beta_{1j} = \gamma_{10}. \quad (E.7c)$$

$$\beta_{2j} = \gamma_{20}. \quad (E.7d)$$

$$\beta_{3j} = \gamma_{30}. \quad (E.7e)$$

$$\beta_{4j} = \gamma_{40}. \quad (E.7f)$$

$$\beta_{5j} = \gamma_{50}. \quad (E.7g)$$

A statistically significant and positive coefficient γ_{01} for treatment indicates that the effect of the online course on algebra scores detected in the main analysis is not explained by differences by condition in the amount of time spent on the algebra posttest by AR students (table E-8).

Table E-8. Results of Sensitivity Model 7: Adding Time Spent on Algebra Posttest at Level 1 (Grand Mean Centered).

Variable	Coefficient	Standard error	p-value	Effect size
Intercept	441.86	1.05	< 0.001	
<i>School covariate</i>				
Condition	4.79	1.47	0.002	0.35
Medium-size school in Maine	2.52	1.87	0.185	
Large-size school in Maine	2.91	2.59	0.266	
Small-size school in Vermont	3.90	2.92	0.187	
Medium-size school in Vermont	4.53	3.34	0.179	
Large-size school in Vermont	3.61	2.85	0.211	
<i>Student covariate</i>				
Female	0.88	1.11	0.430	
Receives special education services	-12.67	3.32	<0.001	
Eligible for free or reduced-price lunch	2.58	1.25	0.039	
State mathematics score (standardized) ^a	8.74	1.10	<0.001	
Time spent on Algebra Posttest	0.52	0.10	<0.001	
	Variance	Chi-squared (degrees of freedom)	p-value	
Residual	119.22			
Level 2 (school)	8.98	85.07 (61)	0.022	
Total variance	128.20			

Note: Sample includes 68 schools (35 treatment, 33 control) and 440 AR students (218 treatment, 222 control). Estimates were averaged across 10 multiply imputed datasets. The effect size was calculated using a pooled standard deviation of the outcome for AR students in treatment and control schools that incorporates both within and between imputation variance (13.78).

b. Because Maine and Vermont use different tests, it was necessary to translate scores into a common metric. The scores were standardized by using the mean and standard deviation of the test scores within each state, including only schools participating in the study.

Source: Algebra scores on study-administered Promise Assessment posttest.

Impact of Intervention on AR Students' High School Coursetaking

To determine the robustness of the impact estimates based on the benchmark impact model for high school coursetaking, researchers conducted the same analyses conducted for the algebra posttest:

- Model E.8 includes prior state mathematics assessment scores and study-administered pretest scores at Level 1 (grand mean centered).
- Model E.9 replaces students' prior state mathematics assessment scores with their study-administered pretest scores at Level 1 (grand mean centered).
- Model E.10 does not adjust for baseline mathematics achievement by excluding students' prior state mathematics assessment scores at Level 1.
- Model E.11 excludes all covariates at Level 1 and Level 2.
- Model E.12 tests the benchmark impact model on observed (nonimputed) data only.
- Model E.13 combines the 34 schools that share an online teacher into 8 "pseudo-schools" for treatment students and uses the standard school for all control students.

All but one of these sensitivity analyses is consistent with the results of the benchmark impact analysis model, where the estimated logit coefficient was 1.10 ($p = 0.007$, odds ratio = 2.99) (table E-9). In model E.9, in which students' state mathematics assessment scores are replaced with their study-administered pretest scores, the treatment effect became nonsignificant ($p = 0.037$), using an alpha value of 0.025 that accounts for multiple comparisons. The significant difference by condition on the pretest may (at least in part) explain this change in significance. In each of the other sensitivity analyses, the effect of the intervention on AR students' high school coursetaking was statistically significant, with AR students in treatment schools more likely to follow an advanced course sequence than their counterparts in control schools.

Table E-9. Summary of Sensitivity Analyses Testing the Robustness of the Effect of Condition on AR Students’ High School Coursetaking

Model	Logit coefficient (standard error)	p-value	Odds ratio (95% confidence interval)
E.8 includes prior state mathematics and study-administered pretest scores as covariates at Level 1	0.97 (0.39)	0.017	2.63 (1.20, 5.78)
E.9 replaces state mathematics with study-administered pretest scores as covariates at Level 1	0.82 (0.39)	0.037	2.28 (1.05, 4.94)
E.10 excludes state mathematics and study-administered pretest scores as covariates at Level 1	0.96 (0.38)	0.014	2.60 (1.22, 5.53)
E.11 excludes all covariates at Level 1 and Level 2	0.89 (0.35)	0.014	2.44 (1.21, 4.92)
E.12 tests benchmark impact model using observed (nonimputed) data only	1.17 (0.40)	0.005	3.22 (1.46, 7.12)
E.13 clusters treatment students who share an online teacher into “pseudo-schools” and control students by their standard school	1.08 (0.45)	0.020	2.94 (1.20, 7.22)

AR is algebra ready.

Note: Sample includes 68 schools (35 treatment, 33 control) and 440 AR students (218 treatment, 222 control). Estimates for all models except E.12 are averaged across 10 multiply imputed datasets. Model E.11 includes 68 schools (35 treatment, 33 control) and 424 AR students (210 treatment, 214 control); 16 students were missing data on the outcome or 1 covariate (estimates are based on observed data only). The sample size of 424 is different from the analytic sample of 440 because this model tests a sensitivity analysis using only observed (nonimputed) data. Coursetaking sequences were coded as advanced or not advanced. Model E.13 excludes state by size blocking covariates at Level 2, given that they do not apply to online teachers. *Source:* Coursetaking data collected from high schools study students attended in 2009/10.

Model E.8

Model E.8 is identical to the model estimated for the benchmark analysis, except that students’ study-administered pretest scores are added as an additional adjustment for baseline mathematics achievement at Level 1. As was the case in the benchmark analysis, all covariates except the treatment indicator were centered on the grand mean.

$$\eta_{ij} = \beta_{0j} + \beta_{1j} (StateMath_{ij} - StateMath..) + \beta_{2j} (Pretest_{ij} - Pretest..) + \beta_{3j} (SpEd_{ij} - SpEd..) + \beta_{4j} (FRL_{ij} - FRL..) + \beta_{5j} (Female_{ij} - Female..) \quad (E.8a)$$

$$\text{where } \eta_{ij} = \log (\phi_{ij} / 1 - \phi_{ij})$$

$$\beta_{0j} = \gamma_{00} + \gamma_{01} TRT_j + \gamma_{02} (MaineMED_j - MaineMED..) + \gamma_{03} (MaineLG_j - MaineLG..) + \gamma_{04} (VermontSM_j - VermontSM..) + \gamma_{05} (VermontMED_j - VermontMED..) + \gamma_{06} (VermontLG_j - VermontLG..) + u_{0j} \quad (E.8b)$$

$$\beta_{1j} = \gamma_{10}. \quad (\text{E.8c})$$

$$\beta_{2j} = \gamma_{20}. \quad (\text{E.8d})$$

$$\beta_{3j} = \gamma_{30}. \quad (\text{E.8e})$$

$$\beta_{4j} = \gamma_{40}. \quad (\text{E.8f})$$

$$\beta_{5j} = \gamma_{50}. \quad (\text{E.8g})$$

A statistically significant and positive coefficient γ_{01} for treatment indicates that the effect of the online course on high school coursetaking is robust to adding the pretest as an additional covariate (table E-10).

Table E-10. Results of Sensitivity Model 8: Adding Study-Administered Pretest Scores at Level 1 (Grand Mean Centered)

Variable	Logit coefficient	Standard error	p-value	Odds ratio	95% confidence interval
Intercept	-1.06	0.29	0.001	0.35	(0.19, 0.62)
<i>School covariate</i>					
Condition	0.97	0.39	0.017	2.63	(1.20, 5.78)
Medium-size school in Maine	0.26	0.51	0.613	1.29	(0.47, 3.56)
Large-size school in Maine	0.62	0.77	0.421	1.86	(0.40, 8.64)
Small-size school in Vermont	0.60	0.68	0.380	1.83	(0.47, 7.10)
Medium-size school in Vermont	-0.24	0.87	0.779	0.78	(0.14, 4.41)
Large-size school in Vermont	0.08	0.74	0.915	1.08	(0.25, 4.75)
<i>Student covariate</i>					
Female	-0.24	0.25	0.335	0.79	(0.49, 1.28)
Receives special education services	-1.68	1.12	0.136	0.19	(0.02, 1.70)
Eligible for free or reduced-price lunch	-0.06	0.30	0.846	1.06	(0.59, 1.91)
Pretest	0.02	0.01	0.015	1.02	(1.00, 1.04)
State mathematics score (standardized) ^a	0.72	0.29	0.014	2.05	(1.16, 3.62)

AR is algebra ready.

Note: Sample includes 68 schools (35 treatment, 33 control) and 440 AR students (218 treatment, 222 control). Estimates were averaged across 10 multiply imputed datasets. Coursetaking sequences were coded as advanced or not advanced.

a. Because Maine and Vermont use different tests, it was necessary to translate scores into a common metric. The scores were standardized by using the mean and standard deviation of the test scores within each state, including only schools participating in the study.

Source: Coursetaking data collected from high schools study students attended in 2009/10.

Model E.9

Model E.9 is identical to the model estimated for the benchmark analysis, except that students' state mathematics assessment scores are replaced with their scores on the study-administered pretest at Level 1. As was the case in the benchmark analysis, all covariates except the treatment indicator were centered on the grand mean.

$$\eta_{ij} = \beta_{0j} + \beta_{1j}(\text{Pretest}_{ij} - \text{Pretest}..) + \beta_{2j}(\text{SpEd}_{ij} - \text{SpEd}..) + \beta_{3j}(\text{FRL}_{ij} - \text{FRL}..) + \beta_{4j}(\text{Female}_{ij} - \text{Female}..) \quad (\text{E.9a})$$

$$\text{where } \eta_{ij} = \log(\varphi_{ij} / 1 - \varphi_{ij})$$

$$\beta_{0j} = \gamma_{00} + \gamma_{01} TRT_j + \gamma_{02} (MaineMED_j - MaineMED.) + \gamma_{03} (MaineLG_j - MaineLG.) + \gamma_{04} (VermontSM_j - VermontSM.) + \gamma_{05} (VermontMED_j - VermontMED.) + \gamma_{06} (VermontLG_j - VermontLG.) + u_{0j} \quad (E.9b)$$

$$\beta_{1j} = \gamma_{10} \quad (E.9c)$$

$$\beta_{2j} = \gamma_{20} \quad (E.9d)$$

$$\beta_{3j} = \gamma_{30} \quad (E.9e)$$

$$\beta_{4j} = \gamma_{40}. \quad (E.9f)$$

A statistically significant and positive coefficient γ_{01} for treatment would indicate that the effect of the online course on high school coursetaking is robust to replacing students' state mathematics scores with their pretest scores as a different (although endogenous) measure of baseline mathematics achievement (table E-11).

Table E-11. Results of Sensitivity Model 9: Replacing Students' Prior State Mathematics Assessment Scores with Study-Administered Pretest Scores at Level 1 (Grand Mean Centered)

Variable	Logit coefficient	Standard error	p-value	Odds ratio	95% confidence interval
Intercept	-0.95	0.29	0.002	0.39	(0.22, 0.69)
<i>School covariate</i>					
Condition	0.82	0.39	0.037	2.28	(1.05, 4.94)
Medium-size school in Maine	0.21	0.50	0.682	1.23	(0.45, 3.35)
Large-size school in Maine	0.57	0.77	0.456	1.78	(0.39, 8.20)
Small-size school in Vermont	0.53	0.67	0.437	1.69	(0.44, 6.47)
Medium-size school in Vermont	-0.45	0.86	0.599	0.64	(0.12, 3.52)
Large-size school in Vermont	-0.05	0.71	0.948	0.95	(0.23, 3.96)
<i>Student covariate</i>					
Female	-0.31	0.24	0.196	0.731	(0.46, 1.18)
Receives special education services	-1.58	1.11	0.157	0.205	(0.02, 1.84)
Eligible for free or reduced-price lunch	0.00	0.29	0.998	0.999	(0.57, 1.77)
Pretest	0.03	0.01	< 0.001	1.032	(1.02, 1.05)

AR is algebra ready.

Note: Sample includes 68 schools (35 treatment, 33 control) and 440 AR students (218 treatment, 222 control). Estimates were averaged across 10 multiply imputed datasets. Coursetaking sequences were coded as advanced or not advanced.

Source: Coursetaking data collected from high schools study students attended in 2009/10.

As shown in Table E-11, the results for Model 9 vary from the results of the benchmark analysis. The effect of the intervention is not statistically significant in Model 9; $p = 0.037$ (using a Bonferroni correction to yield a statistical significance level of $p = 0.025$).

Model E.10

Model E.10 is identical to the model estimated for the benchmark analysis, except that researchers excluded students' state mathematics assessment scores at Level 1 and controlled only for student demographic characteristics (gender, eligibility for free or reduced priced lunch, special education status) at Level 1 and state by size blocking variables (used for random

assignment) at Level 2. As was the case in the benchmark analysis, all covariates except the treatment indicator were centered on the grand mean.

$$\eta_{ij} = \beta_{0j} + \beta_{1j}(SpEd_{ij} - SpEd..) + \beta_{2j}(FRL_{ij} - FRL..) + \beta_{3j}(Female_{ij} - Female..) \quad (E.10a)$$

$$\text{where } \eta_{ij} = \log(\phi_{ij} / 1 - \phi_{ij})$$

$$\begin{aligned} \beta_{0j} = & \gamma_{00} + \gamma_{01} TRT_j + \gamma_{02} (MaineMED_j - MaineMED..) + \gamma_{03} (MaineLG_j - \\ & MaineLG..) + \gamma_{04} (VermontSM_j - VermontSM..) + \gamma_{05} (VermontMED_j - \\ & VermontMED..) + \gamma_{06} (VermontLG_j - VermontLG..) + u_{0j} \end{aligned} \quad (E.10b)$$

$$\beta_{1j} = \gamma_{10}. \quad (E.10c)$$

$$\beta_{2j} = \gamma_{20}. \quad (E.10d)$$

$$\beta_{3j} = \gamma_{30}. \quad (E.10e)$$

A statistically significant and positive coefficient γ_{01} for treatment indicates that the effect of the online course on high schools coursetaking is robust when not adjusting for students' mathematics achievement at baseline (that is, excluding state mathematics and pretest scores) (table E-12).

Table E-12. Results of Sensitivity Model 10: Excluding Students' Prior State Mathematics Assessment Scores at Level 1

Variable	Logit coefficient	Standard error	p-value	Odds ratio	95% confidence interval
Intercept	-0.99	0.28	0.001	0.37	(0.21, 0.65)
<i>School covariate</i>					
Condition	0.96	0.38	0.014	2.60	(1.22, 5.53)
Medium-size school in Maine	0.30	0.49	0.544	1.35	(0.51, 3.56)
Large-size school in Maine	0.38	0.75	0.611	1.47	(0.33, 6.58)
Small-size school in Vermont	0.56	0.66	0.398	1.75	(0.47, 6.53)
Medium-size school in Vermont	-0.47	0.83	0.573	0.62	(0.12, 3.29)
Large-size school in Vermont	0.28	0.69	0.688	1.32	(0.33, 5.30)
<i>Student covariate</i>					
Female	-0.12	0.23	0.612	0.89	(0.57, 1.40)
Receives special education services	-1.94	1.09	0.077	0.14	(0.02, 1.24)
Eligible for free or reduced-price lunch	-0.12	0.27	0.690	0.90	(0.52, 1.54)

AR is algebra ready.

Note: Sample includes 68 schools (35 treatment, 33 control) and 440 AR students (218 treatment, 222 control). Estimates were averaged across 10 multiply imputed datasets. Coursetaking sequences were coded as advanced or not advanced.

Source: Coursetaking data collected from high schools study students attended in 2009/10.

Model E.11

To examine the relationship between the effect of the intervention on high school coursetaking and the covariates specified in the benchmark impact model, model E.11 tests the treatment effect while excluding students' state mathematics assessment scores and their demographic

characteristics (gender, eligibility for free or reduced priced lunch, special education status) at Level 1 and state by size blocking variables (used for random assignment) at Level 2:

$$\eta_{ij} = \beta_{0j}$$

$$\text{where } \eta_{ij} = \log (\phi_{ij} / 1 - \phi_{ij})$$
(E.11a)

$$\beta_{0j} = \gamma_{00} + \gamma_{01} TRT_j + u_{0j}$$
(E.11b)

A statistically significant and positive coefficient γ_{01} for treatment indicates that the effect of the online course on high school coursetaking is robust when not adjusting for student-level variability in baseline mathematics achievement and demographic characteristics and school-level variability across size and state (table E-13).

Table E-13. Results of Sensitivity Model 11: Excluding Covariates at Level 1 or Level 2

Variable	Logit coefficient	Standard error	p-value	Odds ratio	95% confidence interval
Intercept	-0.90	0.26	0.001	0.41	(0.24, 0.68)
<i>School covariate</i>					
Condition	0.89	0.35	0.014	2.44	(1.21, 4.92)

AR is algebra ready.

Note: Sample includes 68 schools (35 treatment, 33 control) and 440 AR students (218 treatment, 222 control). Estimates were averaged across 10 multiply imputed datasets. Coursetaking sequences were coded as advanced or not advanced.

Source: Coursetaking data collected from high schools study students attended in 2009/10.

Model E.12

To examine whether the effect of the intervention on high school coursetaking is sensitive to the missing data approach, model E.12 tests the benchmark impact model using observed (nonimputed) data only, excluding cases that were missing data for high school coursetaking or one or more covariates (3.6% of all cases). The loss of data reduces the size of the available sample and associated statistical power and may introduce bias into the parameter estimates. To reduce potential bias, researchers included the same covariates in the benchmark impact model (which also predicted missingness). As was the case in the benchmark analysis, all covariates except the treatment indicator were centered on the grand mean.

$$\eta_{ij} = \beta_{0j} + \beta_{1j} (StateMath_{ij} - StateMath..) + \beta_{2j} (SpEd_{ij} - SpEd..) + \beta_{3j} (FRL_{ij} - FRL..) + \beta_{4j} (Female_{ij} - Female..)$$
(E.12a)

$$\text{where } \eta_{ij} = \log (\phi_{ij} / 1 - \phi_{ij})$$

$$\beta_{0j} = \gamma_{00} + \gamma_{01} TRT_j + \gamma_{02} (MaineMED_j - MaineMED..) + \gamma_{03} (MaineLG_j - MaineLG..) + \gamma_{04} (VermontSM_j - VermontSM..) + \gamma_{05} (VermontMED_j - VermontMED..) + \gamma_{06} (VermontLG_j - VermontLG..) + u_{0j}$$
(E.12b)

$$\beta_{1j} = \gamma_{10}$$
(E.12c)

$$\beta_{2j} = \gamma_{20}$$
(E.12d)

$$\beta_{3j} = \gamma_{30} \quad (\text{E.12e})$$

$$\beta_{4j} = \gamma_{40}. \quad (\text{E.12f})$$

A statistically significant and positive coefficient γ_{01} for treatment indicates that the effect of the online course on high school coursetaking is robust to the method of handling missing data (multiply imputed versus observed only) (table E-14).

Table E-14. Results of Sensitivity Model 12: Including Observed (Nonimputed) Data Only

Variable	Logit coefficient	Standard error	p-value	Odds ratio	95% confidence interval
Intercept	-1.20	0.30	< 0.001	0.30	(0.16, 0.55)
<i>School covariate</i>					
Condition	1.17	0.40	0.005	3.22	(1.46, 7.12)
Medium-size school in Maine	0.35	0.51	0.492	1.42	(0.52, 3.90)
Large-size school in Maine	0.60	0.78	0.443	1.82	(0.39, 8.55)
Small-size school in Vermont	0.77	0.68	0.264	2.16	(0.55, 8.44)
Medium-size school in Vermont	-0.35	0.86	0.686	0.70	(0.13, 3.93)
Large-size school in Vermont	0.10	0.72	0.889	1.11	(0.26, 4.70)
<i>Student covariate</i>					
Female	-0.20	0.25	0.416	0.82	(0.51, 1.33)
Receives special education services	-2.13	1.14	0.062	0.12	(0.01, 1.12)
Eligible for free or reduced-price lunch	0.09	0.28	0.749	1.09	(0.63, 1.90)
State mathematics score (standardized) ^a	1.26	0.24	< 0.001	3.51	(2.21, 5.58)

AR is algebra ready.

Note: Sample includes 68 schools (35 treatment, 33 control) and 424 AR students (210 treatment, 214 control); 16 students were missing data on the outcome or 1 covariate. The sample size of 424 is different from the analytic sample of 440 because this table represents a sensitivity analysis using only observed (nonimputed) data. Coursetaking sequences were coded as advanced or not advanced.

a. Because Maine and Vermont use different tests, it was necessary to translate scores into a common metric. The scores were standardized by using the mean and standard deviation of the test scores within each state, including only schools participating in the study.

Source: Coursetaking data collected from high schools participating students attended in 2009/10.

Model E.13

High school coursetaking outcomes for treatment students in schools that share an online teacher may be affected in similar ways by specific qualities and background of the online teacher (for example, the teacher's knowledge or experience teaching online) and are not independent. To examine whether the observed treatment effect on high school coursetaking in the benchmark analysis is robust to the clustering of students within online teachers, researchers tested a model similar to the model estimated for the benchmark analysis, with two exceptions. First, treatment students were clustered at Level 2 within the eight online Algebra I teachers, and control students were clustered within their standard schools. Second, because school-level covariates (school state and size) do not apply to online teachers, only the treatment indicator was included in this model at Level 2. As was the case in the benchmark analysis, all covariates except the treatment indicator were centered on the grand mean.

$$\eta_{ij} = \beta_{0j} + \beta_{1j}(\text{StateMath}_{ij} - \text{StateMath}_{..}) + \beta_{2j}(\text{SpEd}_{ij} - \text{SpEd}_{..}) + \beta_{3j}(\text{FRL}_{ij} - \text{FRL}_{..}) + \beta_{4j}(\text{Female}_{ij} - \text{Female}_{..}) \quad (\text{E.13a})$$

$$\text{where } \eta_{ij} = \log(\phi_{ij} / 1 - \phi_{ij})$$

$$\beta_{0j} = \gamma_{00} + \gamma_{01} \text{TRT}_j + u_{0j} \quad (\text{E.13b})$$

$$\beta_{1j} = \gamma_{10} \quad (\text{E.13c})$$

$$\beta_{2j} = \gamma_{20} \quad (\text{E.13d})$$

$$\beta_{3j} = \gamma_{30} \quad (\text{E.13e})$$

$$\beta_{4j} = \gamma_{40} \quad (\text{E.13f})$$

A statistically significant and positive coefficient γ_{01} for treatment indicates that the effect of the online course on high school coursetaking is robust to the unit of clustering at Level 2 for treatment students by using online teacher instead of school (table E-15).

Table E-15. Results of Sensitivity Model 13: Pseudo-School Level 2 Clusters in Estimation of AR Students' High School Coursetaking

Variable	Logit coefficient	Standard error	p-value	Odds ratio	95% confidence interval
Intercept	-1.05	0.26	< 0.001	0.35	(0.21, 0.59)
<i>School covariate</i>					
Condition	1.08	0.45	0.020	2.94	(1.20, 7.22)
<i>Student covariate</i>					
Female	-0.14	0.23	0.555	0.87	(0.56, 1.37)
Receives special education services	-1.85	1.08	0.088	0.16	(0.02, 1.32)
Eligible for free or reduced-price lunch	0.05	0.28	0.867	1.05	(0.60, 1.82)
State mathematics score (standardized) ^a	1.07	0.21	< 0.001	2.91	(1.91, 4.44)

AR is algebra ready.

Note: Sample includes 68 schools (35 treatment, 33 control) and 440 AR students (218 treatment, 222 control). Estimates were averaged across 10 multiply imputed datasets. Coursetaking sequences were coded as advanced or not advanced.

a. Because Maine and Vermont use different tests, it was necessary to translate scores into a common metric. The scores were standardized by using the mean and standard deviation of the test scores within each state, including only schools participating in the study.

Source: Coursetaking data collected from high schools participating students attended in 2009/10.

Impact of Intervention on N-AR Students' Test Scores

To determine the robustness of the impact estimates based on the benchmark impact model of N-AR students algebra scores, researchers conducted the following sensitivity analyses:

- Model E.14 includes prior state mathematics assessment scores and study-administered pretest scores at Level 1 (grand mean centered).
- Model E.15 replaces students' prior state mathematics assessment scores with their study-administered pretest scores at Level 1 (grand mean centered).
- Model E.16 does not adjust for baseline mathematics achievement by excluding students' prior state mathematics assessment scores at Level 1.
- Model E.17 A excludes all covariates at Level 1 and Level 2.
- Model E.18 tests the benchmark impact model on observed (nonimputed) data only.

All of the sensitivity analyses are consistent with the results of the benchmark impact analysis model, where the estimated impact was 0.96 ($p = 0.443$, effect size = 0.06) (table E-16). In no analysis was the effect on N-AR students' algebra scores at the end of grade 8 statistically significant.

Table E-16. Summary of Sensitivity Analyses Testing Robustness of Effect of Condition on N-AR Students' Algebra Posttest Scores

Model	Estimated impact (standard error)	p -value	Effect size
E.14 includes state mathematics and study-administered pretest scores as covariates at Level 1	0.58 (1.18)	0.622	0.04
E.15 replaces state mathematics with study-administered pretest scores as covariates at Level 1	0.39 (1.12)	0.726	0.03
E.16 excludes state mathematics and study-administered pretest scores as covariates at Level 1	0.97 (1.24)	0.435	0.06
E.17 excludes all covariates at Level 1 and Level 2	0.61 (1.36)	0.655	0.04
E.18 tests benchmark impact model using observed (nonimputed) data only	1.00 (1.13)	0.379	0.07 ^a

AR is algebra ready. N-AR is not algebra ready.

Note: Sample includes 68 schools (35 treatment, 33 control) and 1,445 N-AR students (744 treatment, 701 control); 4 control schools had no N-AR students. Estimates for all models except E.18 were averaged across 10 multiply imputed datasets. Model E.18 included 68 schools (35 treatment, 33 control) and 1,199 N-AR students (611 treatment, 588 control); 246 students were missing data on the outcome or 1 covariate (estimates are based on observed data only). The sample size of 1,199 is different from the analytic sample of 1,445 because this model tests a sensitivity analysis using only observed (not imputed) data. Effect sizes were calculated using a pooled standard deviation of the outcome for N-AR students in treatment and control schools that incorporates both within and between imputation variance (16.94).

a. The Hedges' g effect size was calculated using a pooled standard deviation of the outcome for N-AR students in treatment and control schools (13.77).

Source: Algebra scores on study-administered Promise Assessment posttests.

Model E.14

Model E.14 is identical to the model estimated for the benchmark analysis, except that students' study-administered pretest scores were added as an additional adjustment for baseline mathematics achievement at Level 1. As was the case in the benchmark analysis, all covariates except the treatment indicator were centered on the grand mean.

$$\begin{aligned} Algebra_{ij} = & \beta_{0j} + \beta_{1j} (StateMath_{ij} - StateMath..) + \beta_{2j} (Pretest_{ij} - Pretest..) + \beta_{3j} (SpEd_{ij} - \\ & SpEd..) + \beta_{4j} (FRL_{ij} - FRL..) + \beta_{5j} (Female_{ij} - Female..) + \varepsilon_{ij}. \end{aligned} \quad (E.14a)$$

$$\begin{aligned} \beta_{0j} = & \gamma_{00} + \gamma_{01} TRT_j + \gamma_{02} (MaineMED_j - MaineMED..) + \gamma_{03} (MaineLG_j - \\ & MaineLG..) + \gamma_{04} (VermontSM_j - VermontSM..) + \gamma_{05} (VermontMED_j - \\ & VermontMED..) + \gamma_{06} (VermontLG_j - VermontLG..) + u_{0j}. \end{aligned} \quad (E.14b)$$

$$\beta_{1j} = \gamma_{10}. \quad (E.14c)$$

$$\beta_{2j} = \gamma_{20}. \quad (E.14d)$$

$$\beta_{3j} = \gamma_{30}. \quad (E.14e)$$

$$\beta_{4j} = \gamma_{40}. \quad (E.14f)$$

$$\beta_{4j} = \gamma_{40}. \quad (E.14g)$$

$$\beta_{5j} = \gamma_{50}. \quad (E.14h)$$

A nonsignificant coefficient γ_{01} for condition indicates that the effect of the online course on algebra scores is not statistically significant, as is the case in the benchmark model (table E-17).

Table E-17. Results of Sensitivity Model 14: Adding Study-Administered Pretest Scores at Level 1 (Grand Mean Centered)

Variable	Coefficient	Standard error	p-value	Effect size
Intercept	429.91	0.97	< 0.001	
School covariate				
Condition	0.58	1.18	0.622	0.04
Medium-size school in Maine	-4.77	1.86	0.013	
Large-size school in Maine	-5.53	2.32	0.020	
Small-size school in Vermont	-8.20	2.88	0.045	
Medium-size school in Vermont	-5.87	2.88	0.045	
Large-size school in Vermont	-5.14	2.21	0.024	
Student covariates				
Female	-1.92	0.89	0.032	
Receives special education services	-2.04	1.49	0.177	
Eligible for free or reduced-price lunch	-0.94	0.85	0.270	
Pretest	0.09	0.02	< 0.001	
State mathematics score (standardized) ^a	2.57	0.71	0.001	
Chi-squared (degrees of freedom)				
	Variance	freedom	p-value	
Residual	210.53			
Level 2 (school)	6.40	97.28 (57)	0.001	
Total variance	216.93			

N-AR is not algebra ready.

Note: Sample includes 68 schools (35 treatment, 33 control) and 1,445 N-AR students (744 treatment, 701 control); 4 control schools had no N-AR students. Estimates were averaged across 10 multiply imputed datasets. The effect size was calculated using a pooled standard deviation of the outcome for N-AR students in treatment and control schools that incorporates both within and between imputation variance (16.94).

a. Because Maine and Vermont use different tests, it was necessary to translate scores into a common metric. The scores were standardized by using the mean and standard deviation of the test scores within each state, including only schools participating in the study.

Source: Algebra scores on study-administered Promise Assessment posttest.

Model E.15

Model E.15 is identical to the model estimated for the benchmark analysis, except that students' state mathematics assessment scores were replaced with their scores on the study-administered pretest at Level 1. As was the case in the benchmark analysis, all covariates except the treatment indicator were centered on the grand mean.

$$Algebra_{ij} = \beta_{0j} + \beta_{1j} (Pretest_{ij} - Pretest..) + \beta_{2j} (SpEd_{ij} - SpEd..) + \beta_{3j} (FRL_{ij} - FRL..) + \beta_{4j} (Female_{ij} - Female..) + \varepsilon_{ij}. \quad (E.15a)$$

$$\begin{aligned} \beta_{0j} = & \gamma_{00} + \gamma_{01} TRT_j + \gamma_{02} (MaineMED_j - MaineMED..) + \gamma_{03} (MaineLG_j - \\ & MaineLG..) + \gamma_{04} (VermontSM_j - VermontSM..) + \gamma_{05} (VermontMED_j - \\ & VermontMED..) + \gamma_{06} (VermontLG_j - VermontLG..) + u_{0j} \end{aligned} \quad (E.15b)$$

$$\beta_{1j} = \gamma_{10}. \quad (E.15c)$$

$$\beta_{2j} = \gamma_{20}. \quad (E.15d)$$

$$\beta_{3j} = \gamma_{30}. \quad (E.15e)$$

$$\beta_{4j} = \gamma_{40}. \quad (E.15f)$$

A nonsignificant coefficient γ_{01} for treatment indicates that the effect of the online course on algebra scores is not statistically significant, as is the case in the benchmark model (table E-18).

Table E-18. Results of Sensitivity Model 15: Replacing Students' Prior State Mathematics Assessment Scores with Study-Administered Pretest Scores at Level 1 (Grand Mean Centered)

Variable	Coefficient	Standard error	p-value	Effect size
Intercept	430.10	0.95	< 0.001	
<i>School covariate</i>				
Condition	0.39	1.12	0.726	0.03
Medium-size school in Maine	-5.13	1.84	0.008	
Large-size school in Maine	-6.20	2.23	0.008	
Small-size school in Vermont	-8.95	2.86	0.003	
Medium-size school in Vermont	-6.67	2.77	0.019	
Large-size school in Vermont	-5.60	2.16	0.012	
<i>Student covariate</i>				
Female	-1.85	0.89	0.039	
Receives special education services	-3.18	1.45	0.033	
Eligible for free or reduced-price lunch	-1.25	0.85	0.142	
Pretest	0.13	0.02	< 0.001	
Chi-squared (degrees of freedom)				
	Variance	freedom	p-value	
Residual	214.52			
Level 2 (school)	4.86	88.14 (57)	0.005	
Total variance	219.38			

N-AR is not algebra ready.

Note: Sample includes 68 schools (35 treatment, 33 control) and 1,445 N-AR students (744 treatment, 701 control); 4 control schools had no N-AR students. Estimates were averaged across 10 multiply imputed datasets. The effect size was calculated using a pooled standard deviation of the outcome for N-AR students in treatment and control schools that incorporates both within and between imputation variance (16.94).

Source: Algebra scores on study-administered Promise Assessment posttest.

Model E.16

Model E.16 is identical to the model estimated for the benchmark analysis, except that researchers excluded students' state mathematics assessment scores at Level 1 and controlled only for student demographic characteristics (gender, eligibility for free or reduced priced lunch, special education status) at Level 1 and state by size blocking variables (used for random assignment) at Level 2. As was the case in the benchmark analysis, all covariates except the treatment indicator were centered on the grand mean.

$$Algebra_{ij} = \beta_{0j} + \beta_{1j}(SpEd_{ij} - SpEd..) + \beta_{2j}(FRL_{ij} - FRL..) + \beta_{3j}(Female_{ij} - Female..) + \epsilon_{ij}. \quad (E.16a)$$

$$\beta_{0j} = \gamma_{00} + \gamma_{01} TRT_j + \gamma_{02}(MaineMED_j - MaineMED..) + \gamma_{03}(MaineLG_j - MaineLG..) + \gamma_{04}(VermontSM_j - VermontSM..) + \gamma_{05}(VermontMED_j - VermontMED..) + \gamma_{06}(VermontLG_j - VermontLG..) + u_{0j}. \quad (E.16b)$$

$$\beta_{1j} = \gamma_{10}. \quad (\text{E.16c})$$

$$\beta_{2j} = \gamma_{20}. \quad (\text{E.16d})$$

$$\beta_{3j} = \gamma_{30}. \quad (\text{E.16e})$$

A nonsignificant coefficient γ_{01} for treatment indicates that the effect of the online course on algebra scores is not statistically significant, as is the case in the benchmark model (table E-19).

Table E-19. Results of Sensitivity Model 16: Excluding Students' Prior State Mathematics Assessment Scores at Level 1

Variable	Coefficient	Standard error	p-value	Effect size
Intercept	430.03	1.02	< 0.001	
<i>School covariate</i>				
Condition	0.97	1.24	0.435	0.06
Medium-size school in Maine	-5.60	1.92	0.005	
Large-size school in Maine	-7.33	2.37	0.003	
Small-size school in Vermont	-9.21	2.97	0.003	
Medium-size school in Vermont	-7.18	2.93	0.018	
Large-size school in Vermont	-5.91	2.31	0.014	
<i>Student covariate</i>				
Female	-1.56	0.91	0.088	
Receives special education services	-6.04	1.37	< 0.001	
Eligible for free or reduced-price lunch	-2.25	0.85	0.009	
Chi-squared (degrees of freedom)				
	Variance		p-value	
Residual	224.10			
Level 2 (school)	7.23	97.06 (57)	0.001	
Total variance	231.33			

N-AR is not algebra ready.

Note: Sample includes 68 schools (35 treatment, 33 control) and 1,445 N-AR students (744 treatment, 701 control); 4 control schools had no N-AR students. Estimates were averaged across 10 multiply imputed datasets. The effect size was calculated using a pooled standard deviation of the outcome for N-AR students in treatment and control schools at posttest that incorporates both within and between imputation variance (16.94).

Source: Algebra scores on study-administered Promise Assessment posttest.

Model E.17

To examine the relationship between the effect of the intervention on algebra scores and the covariates specified in the benchmark impact model, model E.17 tests the treatment effect while excluding students' state mathematics assessment scores and their demographic characteristics (gender, eligibility for free or reduced priced lunch, special education status) at Level 1 and state by size blocking variables (used for random assignment) at Level 2.

$$Algebra_{ij} = \beta_{0j} + \varepsilon_{ij}. \quad (\text{E.17a})$$

$$\beta_{0j} = \gamma_{00} + \gamma_{01} TRT_j + u_{0j}. \quad (\text{E.17b})$$

A nonsignificant coefficient γ_{01} for treatment indicates that the effect of the online course on algebra scores is not statistically significant, as is the case in the benchmark model (table E-20).

Table E-20. Results of Sensitivity Model 17: Excluding Covariates at Level 1 or Level 2

Variable	Coefficient	Standard error	p-value	Effect size
Intercept	429.20	1.00	< 0.001	
<i>School covariate</i>				
Condition	0.61	1.36	0.655	0.04
	Variance	Chi-squared (degrees of freedom)	p-value	
Residual	232.31			
Level 2 (school)	10.77	127.45 (62)	< 0.001	
Total variance	243.08			

N-AR is not algebra ready.

Note: Sample includes 68 schools (35 treatment, 33 control) and 1,445 N-AR students (744 treatment, 701 control); 4 control schools had no N-AR students. Estimates were averaged across 10 multiply imputed datasets. The effect size was calculated using a pooled standard deviation of the outcome for N-AR students in treatment and control schools at posttest that incorporates both within and between imputation variance (16.94).

Source: Algebra scores on study-administered Promise Assessment posttest.

Model E.18

To examine whether the effect of the intervention on algebra posttest scores is sensitive to the missing data approach, model E.18 tests the benchmark impact model using observed (nonimputed) data only, excluding cases that were missing data for the algebra posttest or any covariate in the model (17% of all cases). The loss of data reduces the size of the available sample and associated statistical power and may introduce bias into the parameter estimates. To reduce potential bias, researchers included the same covariates in the benchmark impact model (which also predicted missingness). As was the case in the benchmark analysis, all covariates except the treatment indicator were centered on the grand mean.

$$Algebra_{ij} = \beta_{0j} + \beta_{1j} (StateMath_{ij} - StateMath..) + \beta_{2j} (SpEd_{ij} - SpEd..) + \beta_{3j} (FRL_{ij} - FRL..) + \beta_{4j} (Female_{ij} - Female..) + \varepsilon_{ij}. \quad (E.18a)$$

$$\beta_{0j} = \gamma_{00} + \gamma_{01} TRT_j + \gamma_{02} (MaineMED_j - MaineMED..) + \gamma_{03} (MaineLG_j - MaineLG..) + \gamma_{04} (VermontSM_j - VermontSM..) + \gamma_{05} (VermontMED_j - VermontMED..) + \gamma_{06} (VermontLG_j - VermontLG..) + u_{0j}. \quad (E.18b)$$

$$\beta_{1j} = \gamma_{10}. \quad (E.18c)$$

$$\beta_{2j} = \gamma_{20}. \quad (E.18d)$$

$$\beta_{3j} = \gamma_{30}. \quad (E.18e)$$

$$\beta_{4j} = \gamma_{40}. \quad (E.18f)$$

A nonsignificant coefficient γ_{01} for treatment indicates that the effect of the online course on algebra scores is not statistically significant, as is the case in the benchmark model (table E-21).

Table E-21. Results of Sensitivity Model 18: Including Observed (Nonimputed) Data Only

Variable	Coefficient	Standard error	p-value	Effect size
Intercept	429.66	0.92	< 0.001	
<i>School covariate</i>				
Condition	1.00	1.13	0.379	0.06 ^a
Medium-size school in Maine	-4.47	1.78	0.015	
Large-size school in Maine	-4.97	2.12	0.023	
Small-size school in Vermont	-7.53	2.80	0.010	
Medium-size school in Vermont	-6.66	2.77	0.020	
Large-size school in Vermont	-4.47	2.06	0.034	
<i>Student covariate</i>				
Female	-1.38	0.86	0.109	
Receives special education services	-2.06	1.28	0.106	
Eligible for free or reduced-price lunch	-1.12	0.87	0.198	
State mathematics score (standardized) ^b	4.44	0.56	< 0.001	
	Variance	Chi-squared (degrees of freedom)	p-value	
Residual	211.61			
Level 2 (school)	4.65	85.02 (56)	0.008	
Total variance	216.26			

N-AR is not algebra ready.

Note: Sample includes 68 schools (35 treatment, 33 control) and 1,199 N-AR students (611 treatment, 588 control); 4 control schools had no N-AR students; 246 students were missing data on the outcome or 1 covariate. The sample size of 1,199 is different from the analytic sample of 1,445 because this table represents a sensitivity analysis using only observed (nonimputed) data.

a. The Hedges' g effect size was calculated using a pooled standard deviation of the outcome for N-AR students in treatment and control schools (13.77).

b. Because Maine and Vermont use different tests, it was necessary to translate scores into a common metric. The scores were standardized by using the mean and standard deviation of the test scores within each state, including only schools participating in the study.

Source: Algebra scores on study-administered Promise Assessment posttest.

Impact of Intervention on N-AR Students' Planned Grade 9 Coursetaking

To determine the robustness of the impact estimates based on the benchmark impact model of N-AR students' planned grade 9 coursetaking, researchers conducted the following sensitivity analyses:

- Model E.19 includes prior state mathematics assessment scores and study-administered pretest scores at Level 1 (grand mean centered).
- Model E.20 replaces students' prior state mathematics assessment scores with their study-administered pretest scores at Level 1 (grand mean centered).
- Model E.21 does not adjust for baseline mathematics achievement by excluding students' prior state mathematics assessment scores at Level 1.

- Model E.22 A excludes all covariates at Level 1 and Level 2.
- Model E.23 tests the benchmark impact model on observed (nonimputed) data only.

The results of the sensitivity analyses presented in table E-22 are consistent with the results of the benchmark impact analysis model, where the estimated logit coefficient was 0.78 ($p = 0.099$, odds ratio = 2.18), with one exception. In model E.23, which tested the benchmark impact model using observed data only (dropping 10% of cases for which N–AR students were missing planned coursetaking or one or more covariates at Level 1), the treatment effect became significant ($p = 0.035$, using an alpha value of 0.05), indicating that N–AR students from treatment schools were more likely to enroll in a grade 9 mathematics course at or above Algebra I than N–AR students in control schools. In each of the other sensitivity analyses, the effect of the intervention on N–AR students’ planned school coursetaking was not statistically significant.

Table E-22. Summary of Sensitivity Analyses Testing Robustness of Effect of Condition on N–AR Students’ Planned Grade 9 Coursetaking

Model	Logit coefficient (standard error)	<i>p</i> -value	Odds ratio (95% confidence interval)
E.19 includes state mathematics and study-administered pretest scores as covariates at Level 1	0.71 (0.47)	0.135	2.03 (0.80, 5.17)
E.20 replaces state mathematics with study-administered pretest scores as covariates at Level 1	0.62 (0.41)	0.138	1.87 (0.81, 4.28)
E.21 excludes state mathematics and study-administered pretest scores as covariates at Level 1	0.69 (0.38)	0.074	2.00 (0.93, 4.28)
E.22 excludes all covariates at Level 1 and Level 2	0.34 (0.37)	0.361	1.40 (0.68, 2.91)
E.23 tests benchmark impact model using observed (nonimputed) data only	1.06 (0.49)	0.035	2.90 (1.80, 7.75)

N–AR is not algebra ready.

Note: Sample includes 68 schools (35 treatment, 33 control) and 1,445 N–AR students (744 treatment, 701 control); 4 control schools had no N–AR students. Estimates for all models except E.23 were averaged across 10 multiply imputed datasets. Model E.23 included 68 schools (35 treatment, 33 control) and 1,298 N–AR students (672 treatment, 626 control); 147 students were missing data on the outcome or 1 covariate (estimates are based on observed data only). The sample size of 1,298 is different from the analytic sample of 1,445 because this model tests a sensitivity analysis using only observed (nonimputed) data. Planned courses were coded as representing a course at or above Algebra I or not at or above Algebra I.

Source: Planned courses indicated by study students at end of Grade 8.

Model E.19

Model E.19 is identical to the model estimated for the benchmark analysis, except that students' study-administered pretest scores is added as an additional adjustment for baseline mathematics achievement at Level 1. As was the case in the benchmark analysis, all covariates except the treatment indicator were centered on the grand mean.

$$\eta_{ij} = \beta_{0j} + \beta_{1j} (StateMath_{ij} - StateMath..) + \beta_{2j} (Pretest_{ij} - Pretest..) + \beta_{3j} (SpEd_{ij} - SpEd..) + \beta_{4j} (FRL_{ij} - FRL..) + \beta_{5j} (Female_{ij} - Female..) \quad (E.19a)$$

where $\eta_{ij} = \log (\phi_{ij} / 1 - \phi_{ij})$

$$\begin{aligned} \beta_{0j} = & \gamma_{00} + \gamma_{01} TRT_j + \gamma_{02} (MaineMED_j - MaineMED..) + \gamma_{03} (MaineLG_j - \\ & MaineLG..) + \gamma_{04} (VermontSM_j - VermontSM..) + \gamma_{05} (VermontMED_j - \\ & VermontMED..) + \gamma_{06} (VermontLG_j - VermontLG..) + u_{0j} \end{aligned} \quad (E.19b)$$

$$\beta_{1j} = \gamma_{10} \quad (E.19c)$$

$$\beta_{2j} = \gamma_{20} \quad (E.19d)$$

$$\beta_{3j} = \gamma_{30} \quad (E.19e)$$

$$\beta_{4j} = \gamma_{40} \quad (E.19f)$$

$$\beta_{5j} = \gamma_{50}. \quad (E.19g)$$

A nonsignificant coefficient γ_{01} for condition indicates that the effect of the online course on planned grade 9 coursetaking is not statistically significant, as is the case in the benchmark model (table E-23).

Table E-23. Results of Sensitivity Model 19: Adding Study-Administered Pretest Scores at Level 1 (Grand Mean Centered)

Variable	Logit coefficient	Standard error	p-value	Odds ratio	95% confidence interval
Intercept	1.10	0.35	0.003	3.00	(1.49, 6.05)
<i>School covariate</i>					
Condition	0.71	0.47	0.135	2.03	(0.80, 5.17)
Medium-size school in Maine	1.43	0.57	0.015	4.18	(1.34, 13.08)
Large-size school in Maine	0.82	0.88	0.359	2.26	(0.39, 13.25)
Small-size school in Vermont	0.12	0.61	0.846	0.56	(0.12, 2.70)
Medium-size school in Vermont	-1.74	0.93	0.067	0.18	(0.03, 1.14)
Large-size school in Vermont	0.20	0.84	0.817	1.22	(0.23, 6.53)
<i>Student covariate</i>					
Female	-0.09	0.18	0.608	0.91	(0.64, 1.30)
Receives special education services	-1.24	0.24	< 0.001	0.29	(0.18, 0.46)
Eligible for free or reduced-price	-0.53	0.17	0.002	0.59	(0.43, 0.82)
Pretest	0.02	0.00	< 0.001	1.02	(1.01, 1.03)
State mathematics score	1.24	0.19	< 0.001	3.45	(2.36, 5.05)

N-AR is not algebra ready.

Note: Sample includes 68 schools (35 treatment, 33 control) and 1,445 N-AR students (744 treatment, 701 control); 4 control schools had no N-AR students. Estimates were averaged across 10 multiply imputed datasets. Planned courses were coded as representing a course at or above Algebra I or not at or above Algebra I.

a. Because Maine and Vermont use different tests, it was necessary to translate scores into a common metric. The scores were standardized by using the mean and standard deviation of the test scores within each state, including only schools participating in the study.

Source: Planned courses indicated by study students at end of Grade 8.

Model E.20

Model E.20 is identical to the model estimated for the benchmark analysis, except that students' state mathematics assessment scores were replaced with their scores on the study-administered pretest at Level 1. As was the case in the benchmark analysis, all covariates except the treatment indicator were centered on the grand mean.

$$\eta_{ij} = \beta_{0j} + \beta_{1j} (Pretest_{ij} - Pretest..) + \beta_{2j} (SpEd_{ij} - SpEd..) + \beta_{3j} (FRL_{ij} - FRL..) + \beta_{4j} (Female_{ij} - Female..) \quad (E.20a)$$

$$\text{where } \eta_{ij} = \log (\phi_{ij} / 1 - \phi_{ij})$$

$$\begin{aligned} \beta_{0j} = & \gamma_{00} + \gamma_{01} TRT_j + \gamma_{02} (MaineMED_j - MaineMED..) + \gamma_{03} (MaineLG_j - \\ & MaineLG..) + \gamma_{04} (VermontSM_j - VermontSM..) + \gamma_{05} (VermontMED_j - \\ & VermontMED..) + \gamma_{06} (VermontLG_j - VermontLG..) + u_{0j} \end{aligned} \quad (E.20b)$$

$$\beta_{1j} = \gamma_{10} \quad (E.20c)$$

$$\beta_{2j} = \gamma_{20} \quad (E.20d)$$

$$\beta_{3j} = \gamma_{30} \quad (E.20e)$$

$$\beta_{4j} = \gamma_{40}. \quad (E.20f)$$

A nonsignificant coefficient γ_{01} for treatment indicates that the effect of the online course on planned grade 9 coursetaking not statistically significant, as is the case in the benchmark model (table E-24).

Table E-24. Results of Sensitivity Model 20: Replacing Students' Prior State Mathematics Assessment Scores with their Study-Administered Pretest Scores at Level 1 (Grand Mean Centered)

Variable	Logit coefficient	Standard error	p-value	Odds ratio	95% confidence interval
Intercept	1.00	0.30	0.002	2.72	(1.50, 4.95)
<i>School covariate</i>					
Condition	0.62	0.41	0.138	1.87	(0.81, 4.28)
Medium-size school in Maine	1.11	0.52	0.038	3.02	(1.07, 8.57)
Large-size school in Maine	0.44	0.79	0.579	1.56	(0.32, 7.56)
Small-size school in Vermont	-0.94	0.70	0.188	0.39	(0.10, 1.59)
Medium-size school in Vermont	-1.96	0.84	0.023	0.14	(0.03, 0.75)
Large-size school in Vermont	-0.07	0.73	0.926	0.93	(0.22, 4.03)
<i>Student covariate</i>					
Female	-0.02	0.16	0.877	0.98	(0.71, 1.34)
Receives special education services	-1.63	0.21	< 0.001	0.20	(0.13, 0.30)
Eligible for free or reduced-price lunch	-0.61	0.16	< 0.001	0.54	(0.40, 0.74)
Pretest	0.03	0.00	< 0.001	1.03	(1.03, 1.04)

N-AR is not algebra ready.

Note: Sample includes 68 schools (35 treatment, 33 control), and 1,445 N-AR students (744 treatment, 701 control); 4 control schools had no N-AR students. Estimates were averaged across 10 multiply imputed datasets. Planned courses were coded as representing a course at or above Algebra I or not at or above Algebra I.

Source: Planned courses indicated by study students at end of Grade 8.

Model E.21

Model E.21 is identical to the model estimated for the benchmark analysis, except that researchers excluded students' state mathematics assessment scores at Level 1 and controlled only for student demographic characteristics (gender, eligibility for free or reduced priced lunch, special education status) at Level 1 and state by size blocking variables (used for random assignment) at Level 2. As was the case in the benchmark analysis, all covariates except the treatment indicator were centered on the grand mean.

$$\eta_{ij} = \beta_{0j} + \beta_{1j}(SpEd_{ij} - SpEd..) + \beta_{2j}(FRL_{ij} - FRL..) + \beta_{3j}(Female_{ij} - Female..) \quad (E.21a)$$

$$\text{where } \eta_{ij} = \log(\varphi_{ij} / 1 - \varphi_{ij})$$

$$\begin{aligned} \beta_{0j} = & \gamma_{00} + \gamma_{01} TRT_j + \gamma_{02}(MaineMED_j - MaineMED..) + \gamma_{03}(MaineLG_j - \\ & MaineLG..) + \gamma_{04}(VermontSM_j - VermontSM..) + \gamma_{05}(VermontMED_j - \\ & VermontMED..) + \gamma_{06}(VermontLG_j - VermontLG..) + u_{0j} \end{aligned} \quad (E.21b)$$

$$\beta_{1j} = \gamma_{10} \quad (E.21c)$$

$$\beta_{2j} = \gamma_{20} \quad (E.21d)$$

$$\beta_{3j} = \gamma_{30}. \quad (E.21e)$$

A nonsignificant coefficient γ_{01} for treatment indicates that the effect of the online course on planned grade 9 coursetaking is not statistically significant, as is the case in the benchmark model (table E-25).

Table E-25. Results of Sensitivity Model 21: Excluding Students' Prior State Mathematics Assessment Scores at Level 1

Variable	Logit coefficient	Standard error	p-value	Odds ratio	95% confidence interval
Intercept	0.85	0.27	0.003	2.33	(1.35, 4.03)
<i>School covariate</i>					
Condition	0.69	0.38	0.074	2.00	(0.93, 4.28)
Medium-size school in Maine	0.89	0.48	0.068	2.44	(0.93, 6.36)
Large-size school in Maine	0.15	0.72	0.832	1.17	(0.27, 4.97)
Small-size school in Vermont	-0.87	0.66	0.189	0.42	(0.11, 1.55)
Medium-size school in Vermont	-1.79	0.77	0.023	0.17	(0.04, 0.77)
Large-size school in Vermont	-0.10	0.67	0.883	0.91	(0.24, 3.46)
<i>Student covariate</i>					
Female	0.00	0.15	0.992	1.00	(0.75, 1.33)
Receives special education services	-2.07	0.20	< 0.001	0.13	(0.09, 0.19)
Eligible for free or reduced-price lunch	-0.80	0.15	< 0.001	0.45	(0.33, 0.60)

N-AR is not algebra ready.

Note: Sample includes 68 schools (35 treatment, 33 control) and 1,445 N-AR students (744 treatment, 701 control); 4 control schools had no N-AR students. Estimates were averaged across 10 multiply imputed datasets. Planned courses were coded as at or above Algebra I or not at or above Algebra I.

Source: Planned courses indicated by study students at end of Grade 8.

Model E.22

To examine the relationship between the effect of the intervention on planned grade 9 coursetaking and the covariates specified in the benchmark impact model, model E.22 tested the treatment effect while excluding students' state mathematics assessment scores and their demographic characteristics (gender, eligibility for free or reduced priced lunch, special education status) at Level 1 and state by size blocking variables (used for random assignment) at Level 2.

$$\eta_{ij} = \beta_{0j} \quad \text{where } \eta_{ij} = \log(\phi_{ij} / 1 - \phi_{ij}) \quad (\text{E.22a})$$

$$\beta_{0j} = \gamma_{00} + \gamma_{01} TRT_j + u_{0j} \quad (\text{E.22b})$$

A nonsignificant coefficient γ_{01} for treatment indicates that the effect of the online course on planned grade 9 coursetaking is the same as in the benchmark model (table E-26).

Table E-26. Results of Sensitivity Model 22: Excluding Covariates at Level 1 or Level 2

Variable	Logit coefficient	Standard error	p-value	Odds ratio	95% confidence interval
Intercept	0.86	0.26	0.002	2.35	(1.39, 3.99)
<i>School covariate</i>					
Condition	0.34	0.37	0.361	1.40	(0.68, 2.91)

N–AR is not algebra ready.

Note: Sample includes 68 schools (35 treatment, 33 control) and 1,445 N–AR students (744 treatment, 701 control); 4 control schools had no N–AR students. Estimates were averaged across 10 multiply imputed datasets. Planned courses were coded as at or above Algebra I or not at or above Algebra I.

Source: Planned courses indicated by study students at end of Grade 8.

Model E.23

To examine whether the effect of the intervention on planned grade 9 coursetaking is sensitive to the missing data approach (multiple imputation, details provided in appendix F), model E.23 tests the benchmark impact model using the observed (nonimputed) data only, excluding cases that were missing data for planned grade 9 coursetaking or any covariate in the model (10%). The loss of data reduces the size of the available sample and associated statistical power and may introduce bias into the parameter estimates. To reduce potential bias, researchers included the same covariates in the benchmark impact model (which also predicted missingness). As was the case in the benchmark analysis, all covariates except the treatment indicator were centered on the grand mean.

$$\eta_{ij} = \beta_{0j} + \beta_{1j} (StateMath_{ij} - StateMath..) + \beta_{2j} (SpEd_{ij} - SpEd..) + \beta_{3j} (FRL_{ij} - FRL..) + \beta_{4j} (Female_{ij} - Female..) \quad (E.23a)$$

$$\text{where } \eta_{ij} = \log (\varphi_{ij} / 1 - \varphi_{ij})$$

$$\begin{aligned} \beta_{0j} = & \gamma_{00} + \gamma_{01} TRT_j + \gamma_{02} (MaineMED_j - MaineMED..) + \gamma_{03} (MaineLG_j - \\ & MaineLG..) + \gamma_{04} (VermontSM_j - VermontSM..) + \gamma_{05} (VermontMED_j - \\ & VermontMED..) + \gamma_{06} (VermontLG_j - VermontLG..) + u_{0j} \end{aligned} \quad (E.23b)$$

$$\beta_{1j} = \gamma_{10} \quad (E.23c)$$

$$\beta_{2j} = \gamma_{20} \quad (E.23d)$$

$$\beta_{3j} = \gamma_{30} \quad (E.23e)$$

$$\beta_{4j} = \gamma_{40}. \quad (E.23f)$$

A significant and positive coefficient γ_{01} for treatment indicates that, unlike in the benchmark model, N–AR students in treatment schools were more likely to enroll in an intermediate course sequence than N–AR students in control schools (table E-27).

Table E-27. Results of Sensitivity Model 23: Observed (Nonimputed) Data Only

Variable	Logit coefficient	Standard error	p-value	Odds ratio	95% confidence interval
Intercept	0.99	0.35	0.008	2.68	(1.32, 5.45)
<i>School covariate</i>					
Condition	1.06	0.49	0.035	2.90	(1.08, 7.75)
Medium-size school in Maine	1.47	0.64	0.026	4.35	(1.20, 15.70)
Large-size school in Maine	0.83	0.97	0.397	2.28	(0.33, 15.78)
Small-size school in Vermont	-1.18	0.85	0.168	0.31	(0.06, 1.67)
Medium-size school in Vermont	-2.35	1.00	0.023	0.10	(0.01, 0.71)
Large-size school in Vermont	0.13	0.89	0.884	1.14	(0.19, 6.78)
<i>Student covariate</i>					
Female	-0.17	0.18	0.347	0.85	(0.60, 1.20)
Receives special education services	-1.11	0.25	< 0.001	0.33	(0.20, 0.54)
Eligible for free or reduced-price lunch	-0.49	0.18	0.006	0.61	(0.44, 0.87)
State mathematics score	2.01	0.16	< 0.001	7.43	(5.48, 10.07)

N-AR is not algebra ready.

Note: Sample includes 68 schools (35 treatment, 33 control) and 1,298 N-AR students (672 treatment, 626 control); 4 control schools had no N-AR students; 147 students were missing data on the outcome or 1 covariate. The sample size of 1,298 is different from the analytic sample of 1,445 because this table represents a sensitivity analysis using only observed (not imputed) data. Planned courses were coded as at or above Algebra I or not at or above Algebra I.

- a. Because Maine and Vermont use different tests, it was necessary to translate scores into a common metric. The scores were standardized by using the mean and standard deviation of the test scores within each state, including only schools participating in the study.

Source: Planned courses indicated by study students at end of Grade 8.

Although the result from Model 23 varied from the benchmark analysis result, both models were conducted to test a secondary research question about whether the offering of online Algebra I to AR students had any significant negative side effects on N-AR students. In all of the sensitivity analyses (including Model 23), the results indicated that the effect of the intervention was not significantly negative on N-AR students' planned coursetaking.

APPENDIX F: MISSING DATA AND MULTIPLE IMPUTATION

This appendix describes the approach used for handling missing data. It describes the rates and patterns of missing data in the study, analyses conducted to identify student- and school-level predictors of missing data, the models used for multiple imputation, and provides graphical and numeric diagnostics that display the results of the imputation.

Imputation Sample

Table F-1 displays the rates of missing data for both covariates and outcome measures. The rates of missing data were not statistically significantly different by treatment status.

Table F-1. Percentage of Missing Cases on Measures in Impact Analyses

Variable	AR students				N-AR students			
	Total	Treatment schools	Control schools	<i>p</i> -value	Total	Treatment schools	Control schools	<i>p</i> -value
<i>Covariate</i>								
Pretest	1	< 1	2	0.298	4	4	4	0.829
State mathematics score	< 1	< 1	< 1	0.582	3	3	3	0.778
Gender	0	0	0		< 1	< 1	< 1	0.466
Eligible for free or reduced-price lunch	< 1	< 1	1	0.351	3	3	3	0.982
Receiving special education services	< 1	< 1	< 1	0.582	2	2	2	0.808
<i>Outcome</i>								
Algebra posttest	1	< 1	2	0.435	14	15	13	0.737
General mathematics posttest	< 1	< 1	1	0.353	7	7	7	0.846
Planned grade 9 course	3	1	5	0.081	7	6	7	0.996
High school coursetaking	3	3	3	0.754	—	—	—	—

AR is algebra ready. N-AR is not algebra ready. — is not available.

Note: Sample includes 68 schools (35 treatment, 33 control); 440 AR students (218 treatment, 222 control); and 1,445 N-AR students (744 treatment, 701 control). Estimates represent only missing data that were subsequently imputed. Statistical comparisons between treatment and control account for the clustering of students within schools. High school coursetaking data were collected only for AR students.

Source: Study team records.

Missing Data Patterns

To identify patterns of missing data, researchers first examined the descriptive statistics for students with missing outcome data and those with complete data (tables F-2 through F-5).

Table F-2. Descriptive Statistics for AR Students with Missing Algebra Posttest Data and AR Students with Complete Data

Characteristic	Overall sample		Missing algebra posttest data		Complete algebra posttest data	
	Number	Percent	Number	Percent	Number	Percent
Total sample	440	100	6	1	434	99
Eligible for free or reduced-price lunch (percent)	139	32	3	50	136	31
Receives special education services (percent)	15	3	0	0	15	3
Has limited English proficiency (percent)	15	3	0	0	15	3
Female (percent)	214	49	≤ 3	≤ 50	≥ 211	≥ 48
Racial/ethnic minority (percent)	29	7	0	0	29	7
	Number	Mean	Number	Mean	Number	Mean
Grade 7 score on state mathematics assessment (standardized) ^a	437	0.95 (0.69)	6	1.16 (1.07)	431	0.95 (0.68)
Fall 2008 pretest score (Promise Assessment) ^b	435	349.87 (23.27)	5	360.60 (19.37)	430	349.74 (23.30)

Note: Sample included 440 students. Observed data were used to populate table. Figures in parentheses are standard deviations.

a. Because Maine and Vermont use different tests, it was necessary to translate scores into a common metric. The scores were standardized by using the mean and standard deviation of the test scores within each state, including only schools participating in the study.

b. The Promise Assessment test was administered in the first month of the school year and is therefore not a pure pretreatment measure.

Source: Maine state department of education and Vermont supervisory unions, study records.

Table F-3. Descriptive Statistics for AR Students with Missing High School Coursetaking Data and AR Students with Complete Data

Characteristic	Overall sample		Missing high school coursetaking data		Complete high school coursetaking data	
	Number	Percent	Number	Percent	Number	Percent
Overall	440	100	13	3	427	97
Eligible for free or reduced-price lunch (percent)	139	32	6	46	133	31
Receives special education services (percent)	15	3	≤ 3	≤ 23	≥ 12	≥ 2
Has limited English proficiency (percent)	15	3	≤ 3	≤ 23	≥ 12	≥ 2
Female (percent)	214	49	5	38	209	49
Racial/ethnic minority (percent)	29	7	≤ 3	≤ 23	≥ 26	≥ 6
	Number	Mean	Number	Mean	Number	Mean
Grade 7 score on state mathematics assessment (standardized) ^a	437	0.95 (0.69)	13	0.96 (0.69)	424	0.96 (0.69)
Fall 2008 pretest score (Promise Assessment) ^b	435	349.87 (23.27)	13	349.94 (23.50)	422	347.54 (14.19)

Note: Sample includes 440 students. Observed data were used to populate table. Figures in parentheses are standard deviations.

a. Because Maine and Vermont use different tests, it was necessary to translate scores into a common metric. The scores were standardized by using the mean and standard deviation of the test scores within each state, including only schools participating in the study.

b. The Promise Assessment test was administered in the first month of the school year and is therefore not a pure pretreatment measure.

Source: Maine state department of education and Vermont supervisory unions, study records.

Table F-4. Descriptive Statistics for N–AR Students with Missing Algebra Data and N–AR Students with Complete Data

Characteristic	Overall sample		Missing algebra posttest data		Complete algebra posttest data	
	Number	Percent	Number	Percent	Number	Percent
Overall	1,445	100	204	14	1,241	86
Eligible for free or reduced-price lunch (percent)	670	46	127	62	543	44
Receives special education services(percent)	252	17	58	28	194	16
Has limited English proficiency (percent)	43	3	11	5	32	3
Female (percent)	717	50	111	54	611	49
Racial/ethnic minority (percent)	75	5	18	9	57	5
	Number	Mean	Number	Mean	Number	Mean
Grade 7 score on state mathematics assessment (standardized) ^a	1,403	–0.24 (0.86)	191	–0.55 (0.95)	1,212	–0.19 (0.84)
Fall 2008 pretest score (Promise Assessment) ^b	1,384	312.60 (27.23)	181	304.52 (28.47)	1,203	313.81 (26.84)

Note: Sample includes 1,445 students. Observed data were used to populate table. Figures in parentheses are standard deviations.

a. Because Maine and Vermont use different tests, it was necessary to translate scores into a common metric. The scores were standardized by using the mean and standard deviation of the test scores within each state, including only schools participating in the study.

b. The Promise Assessment test was administered in the first month of the school year and is therefore not a pure pretreatment measure.

Source: Maine state department of education and Vermont supervisory unions, study records..

Table F-5. Descriptive Statistics for N–AR Students with Missing Planned Grade 9 Coursetaking Data versus N–AR Students with Complete Data

Characteristic	Overall sample		Missing planned grade 9 coursetaking data		Complete planned grade 9 coursetaking data	
	Number	Percent	Number	Percent	Number	Percent
Overall	1,445	100	96	7	1,349	93
Eligible for free or reduced-price lunch (percent)	670	46	69	72	601	45
Receives special education services(percent)	252	17	29	30	223	17
Has limited English proficiency (percent)	43	3	8	8	35	3
Female (percent)	717	50	44	46	673	50
Racial/ethnic minority (percent)	75	5	9	9	66	5
	Number	Mean	Number	Mean	Number	Mean
Grade 7 score on state mathematics assessment (standardized) ^a	1,403	0.24 (0.86)	91	0.35 (1.22)	1,312	0.23 (0.83)
Fall 2008 pretest score (Promise Assessment)	1,384	312.60 (27.23)	82	304.85 (29.00)	1,302	313.09 (27.05)

Note: Sample includes 1,445 students. Observed data were used to populate table. Figures in parentheses are standard deviations.

a. Because Maine and Vermont use different tests, it was necessary to translate scores into a common metric. The scores were standardized by using the mean and standard deviation of the test scores within each state, including only schools participating in the study.

b. The Promise Assessment test was administered in the first month of the school year and is therefore not a pure pretreatment measure.

Source: Maine state department of education and Vermont supervisory unions, study records.

Researchers then examined the extent to which student and school baseline characteristics were related to missingness. Given limited missing data (1%–3%) for the AR sample and a smaller sample size ($n = 440$), there was not sufficient statistical power to detect missing data patterns. Consequently, analyses of missing data patterns are reported only for the N–AR sample (64 study schools, 1,445 students).⁵⁸

To test whether missing data were predicted by any of the covariates included in the impact model and sensitivity analyses, researchers conducted a series of exploratory logistic regression analyses. They created four binary outcome variables that captured whether a student was missing data on the pretest, the general mathematics posttest, the algebra posttest, or grade 9 enrollment. For these four variables, a value of 0 represented complete data and a value of 1 represented missing data. Researchers then regressed the missing data indicators on each covariate in the impact and sensitivity models, controlling for treatment status. They ran separate models for each covariate (that is, the model for gender included only gender and treatment status as predictors of missing pretest) and each missing outcome (that is, separate models were tested for missing pretest, missing general mathematics, missing algebra, and missing planned grade 9 enrollment data). All significant predictors (and those that approached significance at $p < .10$) were then included in the imputation models.

Results indicated systematic differences between students missing data and those with complete data:

- Boys were more likely to have missing data than girls.
- Students eligible for special education services or free or reduced-price lunch were more likely to have missing data than those not receiving these services.
- Students with lower scores on the state mathematics assessment, study-administered pretest, general mathematics posttest, and algebra posttest were more likely to have missing data (on one or more measures) than students with higher scores.
- Students at larger schools were more likely to be missing algebra and coursetaking posttests than students at medium sized schools.
- Students at smaller schools were more likely to be missing pretest scores than students at medium schools.
- State (Maine versus Vermont) was not related to missingness.

Researchers conducted a similar series of logistic regression analyses to identify auxiliary variables not specified in the confirmatory impact models that might help predict missingness. Student-level predictors of missingness included racial/ethnic minority status, English language learner/limited English proficient status, time spent on the pretest, time spent on the general mathematics posttest, and time spent on the algebra posttest.

⁵⁸ This is the total number of N–AR students in treatment and control schools who were not withdrawn from the study by their parents or their schools. (See appendix A, figure A-1, for details about the data collection and analysis sample.)

To identify school-level auxiliary variables, researchers examined school factors from two sources: publicly available data about the schools from the Common Core of Data and sample-specific school-level aggregates of N–AR student data. Out of 20 school characteristics examined, 16 school-level auxiliary variables predicted missing data and were included in the imputation models. From the Common Core of Data, significant predictors of missingness were Title I status, school enrollment, the percentage of students eligible for free or reduced-price lunch, the percentage of minority students, the percentage of girls, and the percentage of students proficient on the state mathematics assessment. From the sample-specific school aggregates, 10 predictors of missingness were significant (gender, limited English proficiency, racial/ethnic minority status, special education status, free or reduced-price lunch status, state mathematics score, pretest score, general mathematics posttest score, and algebra posttest score).

Analyses of missing data patterns suggested that a number of measured student and school characteristics were associated with missingness in a predictable pattern. Based on these analyses, researchers assumed that the data were missing at random (Rubin 1976, 1987; Schafer and Graham 2002).⁵⁹ This assumption implies that missing data depend on observed data and not unobserved data. The missing at random assumption states that once all the observed data (that is, all covariates and auxiliary variables) are included in the study, the patterns of missingness are completely random. Graham (2009) refers to this type of missing data as “conditionally missing at random” to capture the covariate/auxiliary variable predictions. Given the missing at random assumption, multiple imputation was used to adjust for the missing data in the N–AR sample.

Multiple Imputation

With the goal of obtaining accurate parameter estimates for the relationships of interest in the impact models, researchers used multiple imputation by chained equations (in Stata) to impute values for missing student data. This approach involves developing an imputation model, cycling through each of the variables with missing data, and imputing them conditional on all the variables without missing data. The process starts with the variable with the fewest number of missing values and continues until no missing data remain. This process is then repeated multiple times using the new dataset until imputations stabilize (that is, the order in which the variables are imputed no longer matters) and a single dataset with no missing data is created (Stuart et al. 2009). This entire process is repeated to create 10 imputed datasets without missing data.

Imputation Model for N–AR Sample

The model specified to impute the missing N–AR data had the following characteristics:

- It included all significant (at $p < .10$) student-level predictors of missingness in the logistic regression models.
- It included all significant (at $p < .10$) student-level interaction terms that predicted missingness in the logistic regression models.

⁵⁹ However, the missing at random assumption is not testable, and it is not possible to test whether missing data depend on the values that are missing (for example, a student with low posttest scores may be more likely to be absent during posttesting).

- It included all significant (at $p < .10$) school-level predictors of missingness in the logistic regression models to account for the clustered nature of the data.
- It imputed the data for treatment and control samples separately.

In choosing the number of variables to be included in the imputation model, researchers erred on the side of inclusion. The general recommendation for imputation models is to use every available variable in the imputation model (Little and Raghunathan 2004), including the dependent variable (Little and Rubin 2002; Allison 2002). Following these recommendations and those recently published by the Institute of Education Sciences on handling missing data (Puma et al. 2009), researchers included all variables in the impact model and an array of auxiliary variables.

Including interaction terms can increase the specificity of imputation models. Because interaction terms are nonlinear (the product of two variables already included in the imputation model), they introduce nonlinear relationships into the imputed data (Graham 2009). Researchers therefore created student-level interaction terms and tested whether they were related to missing data in a logistic regression model that included the relevant main effects and condition. A total of 17 student-level interaction terms were related to missing data and included in the imputation models:

- pretest $\times$ general mathematics posttest
- algebra posttest $\times$ special education
- general mathematics posttest $\times$ special education
- coursetaking $\times$ general mathematics posttest
- coursetaking $\times$ algebra posttest
- gender $\times$ racial/ethnic minority status
- limited English proficiency $\times$ racial/ethnic minority status
- limited English proficiency $\times$ special education
- limited English proficiency $\times$ eligibility for free or reduced-price lunch
- racial/ethnic minority status $\times$ time on pretest
- gender $\times$ time on general mathematics posttest
- special education $\times$ time on pretest
- special education $\times$ time on general mathematics posttest
- eligibility for free or reduced-price lunch $\times$ time on pretest
- state mathematics score $\times$ time on general mathematics posttest
- time on pretest $\times$ time on general mathematics posttest
- time on pretest $\times$ time on algebra posttest.⁶⁰

⁶⁰ A model with a number of school-level interaction terms did not fit the data as well.

An important consideration when imputing data from cluster randomized trials in school settings is the multilevel structure of the data. To account for the clustered data, the study team included the school-level covariates and auxiliary variables described above that were significant predictors of student-level missing data. This approach allowed the imputation model to benefit from the relationships between school contextual factors and missing student data that are present after controlling for student-level auxiliary variables.⁶¹

Following recommendations by the Institute of Education Sciences (Puma et al. 2009), researchers performed the imputation on treatments and control schools separately.

The final N–AR imputation model included 51 variables:

- 3 outcome variables (student level)
- 10 impact or sensitivity model covariates (5 student level, 5 school level)
- 7 student-level auxiliary variables
- 14 school-level auxiliary variables
- 17 student-level interaction terms

Imputation Model for Algebra-Ready Sample

Because there was not sufficient statistical power to predict patterns of missingness in the AR sample given the limited number of missing data points (1%-3%), the imputation model developed for the N–AR sample was applied to the AR sample. Two additional student-level interactions (general mathematics posttest $\times$ algebra posttest, gender $\times$ time on pretest) that predicted missingness despite limited statistical power were included in the imputation model, as were six additional variables pertaining to high school coursetaking:

- Final high school coursetaking outcome variable
- Three variables used to code the final outcome (grade 9 course, performance in grade 9 course, planned grade 10 course).
- Planned grade 9 course.
- Indicator for whether students doubled up on full year mathematics courses in grade 9 or 10.

⁶¹ Researchers also explored a fixed-effects approach using 63 dummy variables for schools to address the nested data. This model did not converge. Possible specification problems included the large number of dummy variables necessary to capture school differences (models with more than 35 dummy variables are more difficult to use [Graham 2009]). Another potential problem was the fact that the number of students nested within each school varied considerably. When including school-level dummy variables, low-incidence binary variables (such as special education status and limited English proficiency variables in this sample) will be constants within schools. Graham (2009) suggests performing a principal components analysis and examining Eigen values to determine the suitability of using dummy variables with low-incidence binary variables in the model. When this approach was conducted with the study data, the principal components analysis would not converge, suggesting that the dummy variable approach was inappropriate for the current study.

The final AR imputation model included 59 variables:

- 9 outcome variables, including 6 additional variables used to code the high school coursetaking outcome (student level)
- 10 impact or sensitivity model covariates (5 student level, 5 school level)
- 7 student-level auxiliary variables
- 14 school-level auxiliary variables
- 19 student-level interaction terms.

Graphic and Numeric Diagnostics

Graphic diagnostics compare the distribution of observed values, imputed values, and combined observed and imputed values through kernel density plot estimations. “Imputed values” include only those values from each of the 10 datasets that were actually imputed; “observed and imputed values” refer to all the combined imputed and observed values from all 10 complete datasets. Graphic diagnostics can flag a potential misspecification of the multiple imputation model if, for example, the distribution of a particular posttest skewed to the right because students missing the posttest would not be expected to have higher imputed posttest values than students without the missing posttest.

Diagnostics of imputed data do not provide a definitive test of the success of the imputation but rather a means to confirm that the imputed data do not seem overtly unreasonable. Differences between observed and imputed data do not necessarily mean that the imputation model specifications were incorrect. Substantive knowledge must be used in conjunction with the diagnostics when checking for potential misspecifications of the multiple imputation model (Stuart et al. 2009). For example, in this study, because students eligible for free or reduced-price lunch, students receiving special education services, and students with lower pretest and outcome scores were more likely to have missing data, it is reasonable to observe somewhat different distributions of observed and imputed posttest data.

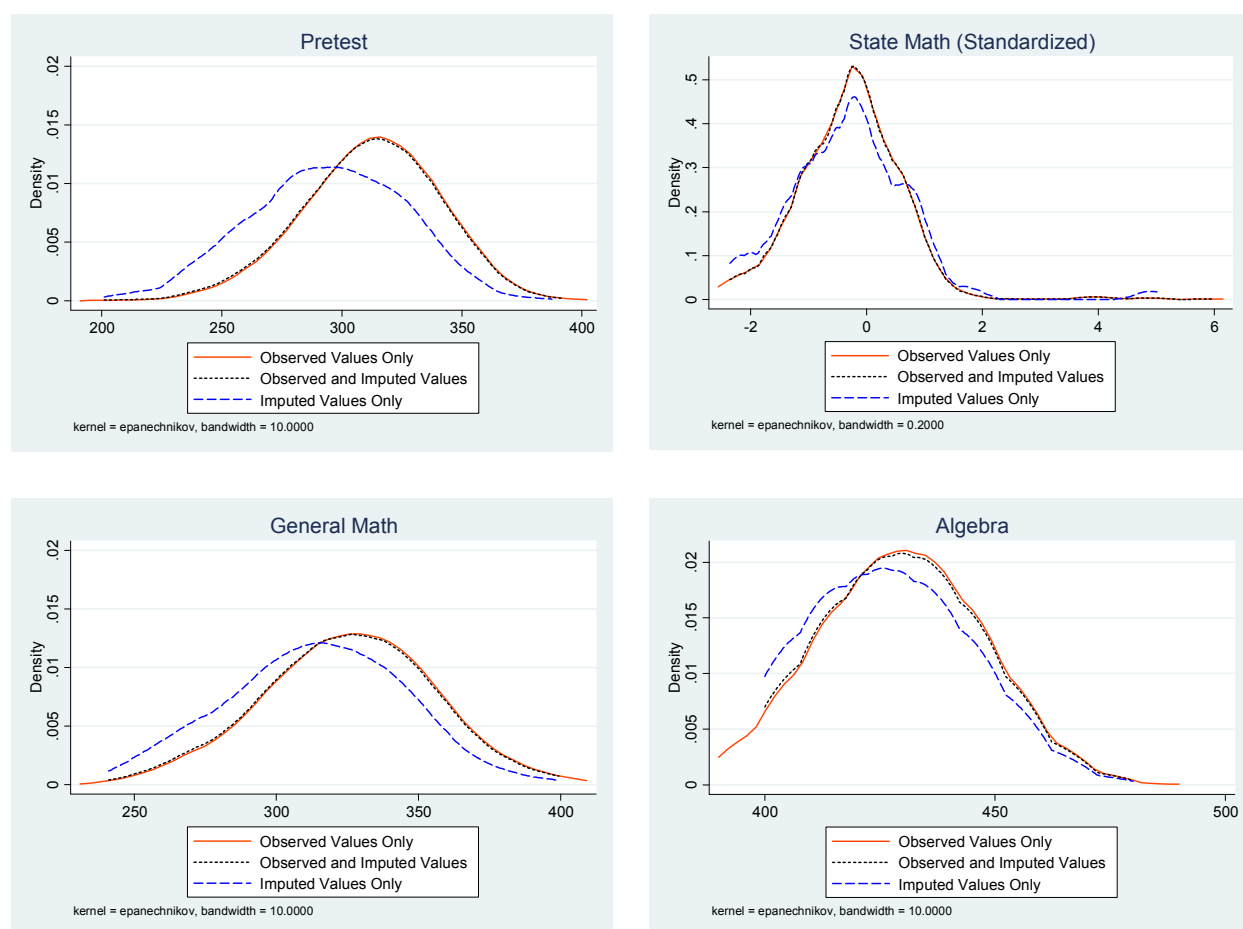
However, because the rates of missing data were relatively low (less than 10% on all variables except algebra posttest for non-algebra ready, on which 14% of cases were missing; less than 3% on all variables for AR students), the best guide by which to judge the reasonableness of the distribution of imputed data is the observed data. Therefore, researchers examined whether the imputed data generated a similar distribution. The imputed data for the AR sample represent a small number of students (six for algebra, four for general mathematics, five for the study-administered pretest, and fewer than four for state mathematics scores). The distributions of imputed data for so few students (less than 3%) are less likely to follow the distribution of observed data in the AR sample (based on 434-437 students).

Figure F-1 shows that for the pretest, state mathematics scores (standardized), general mathematics posttest, and algebra posttest, the imputed and observed distributions are similar to the observed data. As an additional check on the multiple imputation model specification, researchers separately examined the density plot estimations of each of the individual 10 datasets (not presented here). Although there was variation among the 10 datasets, they did not detect any notable deviations from the expected distribution.

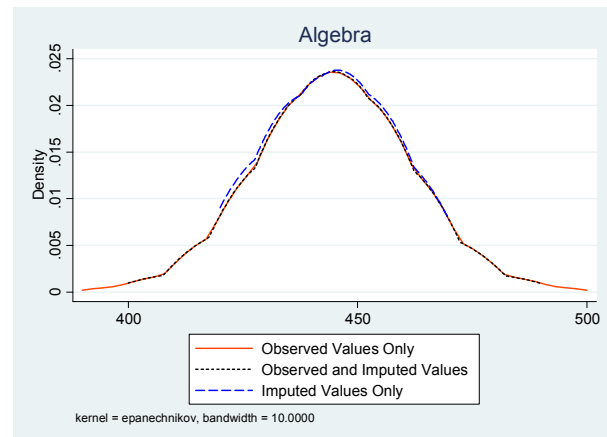
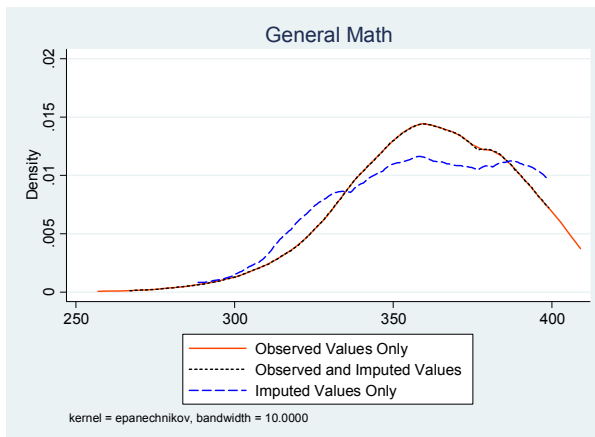
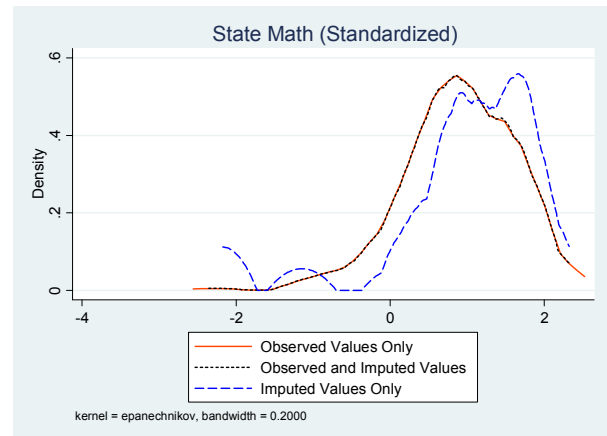
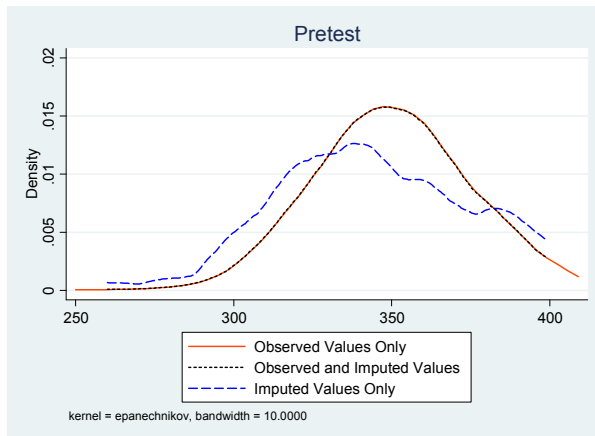
Numeric diagnostics analyzed the mean and the standard deviation of observed values, imputed values, and combined observed and imputed values in search of unreasonably large differences. Table F-6 presents these means and standard deviations for the pretest, state mathematics scores, and algebra and general mathematics posttests for the imputed and nonimputed data. Table F-7 shows the percentage of students in each category of planned grade 9 courses for N-AR students, as well as planned grade 9 courses, actual high school coursetaking, and doubling up in grade 9 or 10 by AR students. The descriptives parallel the graphic diagnostics, with very similar means and standard deviations and distributions of imputed and observed scores, suggesting a robust model of imputation. The tables also present the ratio of the difference between the mean of imputed and observed values to the standard deviation of observed values. For this ratio, Stuart et al. (1999) suggest that an absolute value greater than 2 may indicate that the variable should be flagged for further investigation. None of the ratios from the imputed datasets approached this threshold, and the differences in means and standard deviations were within reason.

Figure F-1. Graphic Diagnostics for Pretest, State Math, General Mathematics Posttest, and Algebra Posttest

a. N-AR Students



b. AR Students



AR is algebra ready. Non-AR is not algebra ready.

Table F-6. Numeric Diagnostics for Achievement Tests: Posttests, Pretest, and Prior Mathematics Scores

Type of student/test	Number	Mean	Standard deviation	Minimum	Maximum	Mean/ standard deviation ratio ^a	Standard deviation ratio ^b
N-AR							
<i>General mathematics posttest</i>							
Observed values	1,342	325.56	28.94	241	399	-0.41	1.06
Imputed values	103	313.61	30.73	241	399		
Observed and imputed	1,445	324.71	29.23	241	399		
<i>Algebra posttest</i>							
Observed values	1,241	429.60	15.29	400	480	-0.25	1.07
Imputed values	204	425.72	16.30	400	480		
Observed and imputed	1,445	429.05	15.50	400	480		
<i>Pretest Promise Assessment</i>							
Observed values	1,384	312.60	27.22	201	392	-0.69	1.16
Imputed values	61	293.91	31.61	201	388		
Observed and imputed	1,445	311.81	27.67	201	392		
<i>State mathematics</i>							
Observed values	1,403	-0.27	0.90	-2.36	5.95	-0.63	1.20
Imputed values	42	-0.30	1.08	-2.36	5.01		
Observed and imputed	1,445	-0.28	0.91	-2.36	5.95		
Algebra ready							
<i>General mathematics posttest</i>							
Observed values	436	361.57	25.14	267	399	-0.01	1.14
Imputed values	4	361.39	28.75	289	399		
Observed and imputed	440	361.56	25.17	267	399		
<i>Algebra posttest</i>							
Observed values	434	444.75	14.10	400	490	-0.07	0.90
Imputed values	6	443.83	12.63	420	470		
Observed and imputed	440	444.73	14.08	400	490		
<i>Pretest Promise assessment</i>							
Observed values	435	349.87	23.25	260	399	-0.22	1.35
Imputed values	5	344.68	31.41	260	399		
Observed and imputed	440	349.81	23.36	260	399		
<i>State mathematics</i>							
Observed values	437	0.90	0.72	-2.36	2.32	1.45	1.53
Imputed values	3	0.94	1.10	-2.17	2.32		
Observed and imputed	440	0.90	0.72	-2.36	2.32		

AR is algebra ready. Non-AR is not algebra ready.

Note: Means and standard deviations are estimated across 10 imputed datasets.

a. Ratio of the difference between the mean of imputed and observed values to the standard deviation of observed values.

b. Ratio of the standard deviation of the imputed values to the standard deviation of the observed values.

Source. Study records.

Table F-7. Numeric Diagnostics for Binary Coursetaking Outcomes

Variable	Not intermediate		Intermediate	
	Number	Percent	Number	Percent
<i>N-AR students</i>				
Planned coursetaking				
Observed values	3,720	28	9,770	72
Imputed values	437	46	523	54
Observed and imputed	4,157	29	10,293	71
	Not advanced		Advanced	
	Number	Percent	Number	Percent
<i>AR students</i>				
Planned coursetaking				
Observed values	2,520	59	1,740	41
Imputed values	77	55	63	45
Observed and imputed	2,597	59	1,803	41
High school coursetaking				
Observed values	2,510	59	1,760	41
Imputed values	73	56	57	44
Observed and imputed	2,583	59	1,817	41
	Did not double up		Doubled up	
	Number	Percent	Number	Percent
Observed values	3,340	79	890	21
Imputed values	99	58	71	42
Observed and imputed	3,439	78	961	22

AR is algebra ready. N-AR is not algebra ready.

Note: Numbers represent total number of students across 10 imputed datasets. For N-AR students, 0 = planned course below Algebra 1, 1 = planned course at or above Algebra 1. For AR students, 0 = planned course at or below Algebra 1, 1 = planned course above Algebra 1.

Source. Study records.

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